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THE UTILISATION OF WOOD-WASTE

THE UTILISATION OF WOOD-WASTE

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ERNST HUBBARD

Translated from the German of the Second Revised and Enlarged Edition

THIRD ENGLISH REVISED AND ENLARGED EDITION

BY

H. B. STOCKS, F.I.C., F.C.S.

WITH FIFTY-ONE ILLUSTRATIONS

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PREFACE

The rational utilisation of waste products is at all times important, but as our industries become more and more developed the working up of the waste or bye-products which may be produced in any process becomes absolutely essential from an economical standpoint.

Many instances could be cited in which a waste product has become one of the chief products, sometimes nearly, if not quite, as important as the material which was first made. This has proved to be the case in many industries, but confining ourselves to the present subject, large quantities of wood-waste are produced as the result of the felling of trees and the conversion of the wood into timber of various kinds. This includes twigs and branches, slabs, shavings, and sawdust, all of which are capable of being utilised for a variety of purposes.

By treatment of such wood-waste it is possible to obtain turpentine, wood oils, tar and pitch, acetic acid, acetone, methyl alcohol, formaldehyde, charcoal, and numerous other products as the result of distillation. It can also be used for heating purposes, gas-making, manufacture of alcohol, dyes, explosives, artificial wood compositions, linoleum, wood wool, wood flour, etc. It is, in fact, used for all these purposes at the present time.

In the pages which follow, the author has given a full account of the many methods of utilising wood-waste, the present edition having been revised and also brought

up to date by the addition of much new material which has appeared since the last edition was published.

It is the author's sincere hope that the information contained in this book will be found to be of interest and value to all those engaged in the wood industries, and also to chemists and others who may have to deal with these products in the course of their employment.

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THE UTILISATION OF WOOD WASTE

INTRODUCTION

Cellulose.—Cellulose is the basic framework of woods and vegetable tissues in general. In a pure state it may be regarded as a carbohydrate, having the same composition as starch and dextrin, although differing from both these in its properties. The composition is represented by the formula $(C_6H_{10}O_5)n$, and its percentage composition is :—

Carbon	44·43
Hydrogen . . .	6·16
Oxygen	49·41
	100·00

Pure cellulose, however, is extremely difficult, if not impossible, to obtain, the nearest approach to it being purified filter paper and bleached cotton, which approximate to the above in composition. In addition to organic impurities, the various forms of cellulose contain mineral matters which are difficult to remove, but they may be practically eliminated by boiling with hydrochloric acid, followed by hydrofluoric acid, and then washing and drying.

Wood is termed a ligno-cellulose, that is to say, it contains, in addition to cellulose, encrusting materials, which

have been referred to by Cross and Bevan as the lignone-complex, perhaps for want of a better designation, seeing that its constitution is not very well understood, and it is regarded as probable that the lignone substance is formed at the expense of the cellulose, since it increases in proportion with the increasing age of the wood; the arguments on this point are, however, not conclusive. The lignone substance differs from cellulose in many particulars, not only in its composition, but also in its reactivity, that is to say, it is much more readily acted upon by reagents such as acids and alkalies, chlorine, etc., and it is differentiated from cellulose also by yielding furfural when heated with dilute hydrochloric acid. From the latter reaction it is evident that it contains pentosans or furfuroids, or, as Cross and Bevan observe, it is in the nature of an oxycellulose.

On treating wood with alkalies or acids, or with oxidising agents such as chlorine, bromine, or nitric acid, or with bisulphites under pressure, the woody substances are attacked, yielding soluble products which may be washed away with water, leaving a residue of more or less pure cellulose.

Among the constituents of the cell-walls of wood may be noted more particularly a material which, although insoluble in water, is soluble in solutions of the alkalies, yielding gummy solutions. This material, known as xylan, or wood gum ($C_5H_8O_4$), is hydrolysed on heating with dilute acids, forming the pentose or sugar xylose ($C_5H_{10}O_5$). It occurs in most woods in small amounts, but in beechwood it is fairly abundant. The product known as wood gum was first obtained and examined by T. Thomsen [1] and Poumarède and Figuier [2]; it has been more recently studied by others.

The elementary composition of wood shows that it

[1] *Journ. Prac. Chem.*, (2), 19, 146.
[2] *Ann.*, 64, 388.

ontains much more carbon (48–50 per cent.) than that alculated from the $C_6H_{10}O_5$ formula, as will be seen from he following analyses :—

ANALYSES OF WOOD BY CHEVANDIER.[1]

Wood.	Calculated on the Ash-free Substance.			
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Beech (mean of 7 analyses) .	49·89	6·07	43·11	0·93
Oak ,, 5 ,, .	50·64	6·03	42·05	1·28
Birch ,, 5 ,, .	50·61	6·23	42·04	1·12
Poplar ,, 3 ,, .	50·31	6·32	42·39	0·98
Willow ,, 2 ,, .	51·75	6·19	41·08	0·98
Brushwood and branches :—				
Beech (mean of 8 analyses) .	50·08	6·23	41·61	1·08
Oak ,, 4 ,, .	50·89	6·16	41·94	1·01
Birch ,, 3 ,, .	51·93	6·31	40·69	1·07
Poplar ,, 2 ,, .	51·02	6·28	41·65	1·05
Willow ,, 2 ,, .	54·03	6·56	37·93	1·48

Gottlieb, and Schödler, and Peterson have also made nalyses of woods, the results being given below :—

ANALYSES OF WOOD BY GOTTLIEB.[2]

Wood.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Beech . . .	49·06	6·11	44·17	0·09	0·57
Oak . . .	50·16	6·03	43·44	—	0·37
Birch . . .	48·88	6·06	44·67	0·10	0·29
Ash . . .	49·18	6·27	43·98	—	0·57
Hornbeam . .	48·99	6·20	44·31	—	0·50
Fir . . .	50·36	5·92	43·39	0·05	0·28
Pine . . .	50·31	6·20	43·08	0·04	0·37

[1] Chevandier, *Ann. Chim. Phys.*, (3), 10, 129.
[2] Gottlieb, *Jour. Prac. Chem.* (2), 28, 385.

ANALYSES OF WOOD BY SCHÖDLER AND PETERSON.

Wood.	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Pure woody fibre	52·65	5·25	42·10
Oak	49·43	6·07	44·50
Ash	49·36	6·075	44·565
Maple	49·80	6·31	43·89
Beech	48·53	6·30	45·17
Birch	48·60	6·375	45·025
Elm	50·19	6·425	43·385
Poplar	49·70	6·31	43·99
Lime	49·41	6·86	43·73
Willow	48·44	6·36	44·80
Fir	49·95	6·41	43·65
Spruce	49·59	6·38	44·02
Scotch pine	49·94	6·25	43·31
Larch	50·11	6·31	43·58

Proximate analyses have also been made by Hugo Müller,[1] the separation of the cellulose being made by the bromine water treatment :—

Wood.	Water.	Cellulose.	Aqueous Extract.	Resin.	Other Non-Cellulose.
Birch	12·48	55·52	2·65	1·14	28·21
Beech	12·57	45·47	2·41	0·41	39·14
Box	12·90	48·14	2·63	0·63	35·70
Ebony	9·40	29·99	9·99	2·54	48·08
Oak	13·12	39·47	12·20	0·91	34·30
Alder	10·70	54·62	2·48	0·87	31·33
Lignum vitæ	10·88	32·22	6·06	15·63	35·21
Lime	10·10	53·09	3·56	3·93	29·33
Chestnut	12·03	52·64	5·41	1·10	28·82
Fir	12·87	53·27	4·05	1·63	28·18
Mahogany	12·39	49·07	9·91	1·02	27·61
Poplar	12·10	62·77	2·88	1·37	20·88
Pine	13·87	56·99	1·26	0·97	26·91
Teak	11·05	43·12	3·93	3·74	38·16
Willow	11·66	55·72	2·65	1·23	28·74

[1] *Pflanzenfaser*, 150.

Reference may also be made in this connection to the researches of Schultze, who obtained the following results :—

	Proximate Composition of Wood.		Composition of Isolated Cellulose.	
	Cellulose.	Non-cellulose.	Carbon.	Hydrogen.
Beech . . .	48·41	51·59	47·71	6·05
Oak . . .	45·87	54·13	44·51	6·00
Alder . . .	47·97	52·03	43·96	5·95
Acacia . . .	52·94	47·06	44·29	6·09
	58·11	41·89	44·54	6·01

The cellulose was separated by treatment of the woods with dilute nitric acid and potassium chlorate and the non-cellulose by difference.

From these results Schultze calculated that the non-cellulose, or lignone-complex in the woods contained 55·3 per cent. of carbon, and had approximately a composition represented by the formula $C_{19}H_{24}O_{10}$, with which Cross and Bevan[1] are in practical agreement. On the other hand, Schuppe[2] deduces the formula for the lignone complex as $C_{19}H_{18}O_8$, and the composition of woody tissue as essentially a combination of this with cellulose : $5C_6H_{10}O_5$, $C_{19}H_{18}O_8$.

[1] Cross and Bevan, *Cellulose*, 1903, p. 177.
[2] W. Schuppe, *Pharm. Jour.* (3), 14, 52.

CHAPTER I

GENERAL OBSERVATIONS ON THE UTILISATION OF SAWDUST

THE various trades and industries which deal with wood in some shape or form, from the simple mountain or forest saw-pit, in which the saw is worked by water power and where therefore no advantage is to be obtained from the combustion of the refuse as fuel, or from the large, well-arranged saw-mill, to the furniture-maker and the cabinet-maker working on the smallest scale, the cutting up of tree trunks, the production of beams and planks, etc., etc., all result in the production of large quantities of saw-dust, which often occasions serious inconvenience to the producers. The amount of this waste product is often so enormous that neither storage room nor means of transport is available, and the substance, by lying in the open air, exposed to all the vicissitudes of weather, either rots away completely, or at least undergoes very considerable decomposition. The transport of sawdust, on account of its bulkiness and the want of means of communication, is in many cases impossible, and many timber producers are very pleased if their neighbours will relieve them of an onerous burden, either free or for a small payment. In the immediate neighbourhood of railways and roads the value of sawdust is somewhat enhanced; nevertheless, even with these facilities, the packing for carriage involves difficulties and the substance can neither be utilised, nor so readily sold, as according to its real value should be the case.

Sawdust, in form and colour, is a very variable material. The product from large saw-mills, being for the most part

obtained by the use of large saws, is coarse and fibrous, and is frequently mixed with fragments of wood and bark; moreover, in consequence of the use of unseasoned wood, it is often damp or even wet. The sawdust produced by those industries which make use of wood is generally finer, less fibrous, and drier, since it is the product of thinner saws with finer teeth; finally the waste obtained by working wood with the rasp is more or less floury. Only the sawdust of the softer woods (the coniferous woods, poplar, lime, etc.) is distinctly fibrous; that from harder woods (oak, beech, walnut) forms a coarser or finer powder, the condition of which depends nevertheless to some extent on the kind of saw used. The colour of sawdust varies with that of the wood from which it is obtained, that from hard woods being usually brownish, that from mahogany reddish, etc.

Since the coarseness of the sawdust is dependent on the kind of saw used, and the degree to which the teeth are set, as also on the dampness of the wood, it follows that the percentage of this product yielded by the original timber is very variable; in large saw-mills, where tree trunks are cut up into baulks and deals, the proportion of sawdust will naturally be larger than in those industries which employ the wood already so prepared, and therefore it is from the former that the largest quantities of sawdust are obtained, and it is the owners of these mills who have the greatest interest in a favourable disposal of the material.

It is of the greatest importance in saw-mills that this waste product should be preserved in as clean a condition as possible, that shavings and chips should be kept out of it, and that it should not be allowed to be injured by getting wet.

The most obvious application of sawdust is, of course, its use as fuel. If only small amounts have to be dealt with, it may be burnt in the ordinary fire-grates by placing it a little at a time upon a coal or wood fire which is in a

vigorous state of combustion. The quantity placed on the fire at one time must never be large, and it must occasionally be loosened with a poker in order to give access to the air necessary for its combustion. To burn larger quantities in the ordinary fire-grates is difficult, in consequence of the lack of a proper air supply, for sawdust is a substance which compacts itself closely, and when in a damp condition is utterly unsuitable for use as a fuel. Special furnaces and fire-grates have therefore for a long time been in use for this purpose, whilst in recent times attempts have been made to consolidate the substance into briquettes before burning it, which attempts have met with a fair amount of success. The furnaces and grates which have been suggested for burning this material, as well as the appliances for charging them regularly with sawdust, and for preventing the burning mass from collapsing, are described in a special section of this book, where the most recent improvements in these appliances will be found. A further step in the utilisation of this waste material is found in the combined employment of it as a fuel and as a source of distillation-products, such as acetic acid, wood-spirit, acetone, etc., which are obtained by submitting wood to destructive distillation. In the same way, exhausted, ground or chipped dye-woods from extract factories and dye works, as well as spent tan bark from the tanneries, can be burnt in any of these furnaces with a similar efficiency, so that in these industries very considerable sums can be saved, which otherwise would have been lost.

The use of sawdust in combination with binding and cementing substances, such as glue, albumin, blood, and resin, to form plastic materials, the so-called *artificial wood*, is already somewhat old and well known, though it is only quite recently that it has been discovered how to cement sawdust together so as to form a really firm decorative material, capable of resisting changes of temperature and damp, and in no respect inferior to expensive but fragile

wood carvings. Amongst these materials should be mentioned the one called *xylolith*, a substance of stony hardness, which, supplied in thin slabs of various colours, is employed for flooring, wainscot, and similar purposes, and has proved very satisfactory.

The production of *blasting powders and gunpowder* from sawdust has been repeatedly attempted, and although the results attained do not promise a very extensive consumption, some of the formulæ for this purpose may well find a place in this work. For the manufacture of *oxalic acid* sawdust is still almost the only raw material available, and affords a profit. The accumulation of sawdust in a great number of localities has, of course, given rise to numerous proposals for its utilisation, some of which, however, have never been put into practice.

Thus, in France, sawdust has long been used instead of sand for drying up ink. Sawdust has the advantage over sand that it is in no way injurious to books, pens, writing-table, etc. And in countries where the minimum postage fee is restricted to letters under $\frac{1}{2}$ oz. in weight, the use of the far heavier sand may easily cause a letter to be over weight. For this purpose the sawdust of hard woods, cut with fine saws, as, for instance, in cutting veneers, is chiefly employed. This is not used in the state in which it is first obtained, but is passed through a coarse sieve, so that splinters of wood may be taken out, and is then freed from dust by shaking it on an extremely fine gauze. As employed it is therefore in a finely granular condition, free from coarse particles and not dusty; the harder the wood the better is the product. Sawdust for this purpose is commonly dyed and perfumed in order to give it a more pleasing appearance. The dyes used are those obtained from coal-tar; 3 to 5 parts of the selected dye are dissolved in 100 parts of water, the sawdust is stirred into the solution and thoroughly wetted therewith, so that a uniform dyeing of every particle may be ensured, and after taking

out from the dye-bath it is dried in moderately heated chambers for the removal of the excess of moisture. Any desired tint can thus be given to the powder, after which it is perfumed by placing it, together with very small quantities of ethereal oils, in vessels which can be closed and rotated until the perfume is uniformly absorbed. This mode of utilisation is especially to be recommended to veneer cutters for working up their sawdust. If the sawdust from the various woods used in these workshops can be collected separately, the mahogany and rosewood could be employed for dyeing the lighter woods. The dark woods could be boiled with water containing a little alum, and the filtered extract used for dyeing alder, cherry, or elm wood, thus communicating to these light woods a mahogany or rosewood appearance.

Sawdust of any sort may also be used in making plastic cements for filling up defective places in woodwork, and it is advantageous for this purpose to use the sawdust of the same kind of wood as that to be filled, rather than to dye another variety of sawdust so as to match the shade.

The use of sawdust as a *packing material* for fragile articles, such as those of sheet metal or glass, is too well known to require remark here; it may, however, be noticed that care should be taken to have it well dried and free from dust. The same is the case with regard to its use in a damp state for sweeping out the floors of dwelling-rooms. Dry, clean sawdust is a good material both for packing and for preserving eggs, and is much preferable to chaff, which is often damp and malodorous. Less known is its use in paint works, for cleaning the paint mills, utensils, cans, etc., from paint residues which cannot be removed with scrapers. The paint is by this means completely removed, leaving the mills clean, and the metal work bright.

For the preparation of a substitute for bone ash, Maxwell Lyte proposes to mix mineral phosphates with peat, saw-

dust, tar, etc., or with animal substances such as blood, and to calcine and pulverise the mixture.

The low conductivity for heat possessed by sawdust is of importance, and has gained for it extensive employment. The intermediate spaces between the joists in houses may advantageously be filled with sawdust instead of with builders' rubbish, which is, often enough, deleterious to health. Its use as a packing material for ice chests and ice houses is well known, and it may also be used with immense advantage for preserving the warmth of green-houses.

The well-known linoleum is manufactured from ground cork refuse mixed with linseed oil and rolled out into sheets; instead of cork powder, sawdust has often been used, or rather the wood-meal obtained by grinding sawdust between millstones, and, especially for the cheaper qualities, has given favourable results. Also in the manufacture of paper, wood-meal has here and there been used as a filling material instead of mineral substances. For laying down floors with cement plates, sawdust is better than sand, as it makes the floor warmer. When sawdust is mixed with pitch in various proportions, with the aid of heat, and the mixture is exposed to great pressure in moulds, a substance is obtained resembling wood, which can be cut, planed, bored, and polished, and which is very hard, tough, and imputrescible. The sawdust must first be baked until it is almost brown-black, which ensures that it is free from water. Plaster and cement planks (sawdust boards) may likewise be prepared by mixing plaster of Paris or cement with sawdust and water and pouring the mixture into suitable moulds; these form a light and yet strong building material. Sawdust with plaster of Paris, or wood-wool refuse with plaster, forms a very suitable material for packing steam boilers, steam pipes, etc.

Combined with asphalt, sawdust is used in the damp-proof course of walls. Roofing felt intended for export

is strewn with sawdust instead of with sand to diminish the weight, and obtain greater elasticity.

Wood-cement is prepared from sawdust, glue, and water-glass (sodium silicate). The addition of sawdust to clay intended for brick-making produces light, porous bricks. These are used for partition walls, and are very poor conductors of heat. By mixing a very large quantity of sawdust with clay and kiln-burning the mixture, a cheap filtering material is obtained, which, as it contains wood-charcoal, serves as a disinfectant. Sawdust mixed with gas-tar forms an admirable damp course for the walls of buildings standing on damp ground. Mixed with balsam of sulphur it gives an elastic material, and with asphalt and a little linseed oil a harder mixture for coating damp walls and cold baths.

In burning black clay pipes, a layer of sawdust and then a layer of pipes are placed in a muffle, which may hold 500 to 600 pipes; the muffle is then luted and heated to a dull red-heat in a furnace for 10 to 12 hours. The sawdust is carbonised, gives up its products of distillation, which are absorbed by the pipes and communicate a black colour to them. About 20 to 50 of the pipes are stuck upon a round disc furnished with pegs, and are held in the smoke of burning straw; they acquire an intense black colour, and are then polished with wax and a stiff brush.

In the manufacture of wall-paper, sawdust and even wood-meal, instead of the usual chopped wool, have been used for making low qualities of velvet paper, the previously dyed sawdust being sifted over the paper, which has been first printed with an adhesive paste; also in other industries fine dyed sawdust may with advantage be employed instead of chopped wool. Wood-meal is used in the manufacture of artificial flowers, to imitate the pollen, and when dyed in pale soft shades has a very good effect.

As *litter* for *cow-sheds*, sawdust is superior to leaves or pine needles, as it is capable of absorbing more liquid than

the latter, and nevertheless furnishes a dry bed for the beasts. Sawdust, especially that consisting of long fibres, saturated with animal excrement, makes a very good manure, because it rots easily.

In the preparation of composts for garden work sawdust is of great importance. To prepare it for use it is laid down in an open shady situation in heaps 75 to 100 cm. (30 to 40 inches) high, and turned over several times a year, until the whole mass is well rotted. This compost is lighter than leaf mould, and for some plants, as for instance orchids, may be used alone, or it may be mixed with cow dung or garden soil to make it heavier, or with heath mould or sand to make it lighter. Another use of sawdust is for the preparation of hotbeds, instead of the tan commonly employed. It gives a higher temperature than tan, and maintains the heat for a full year. It is advisable to mix a little chopped straw with the sawdust to prevent it from becoming too much consolidated, in which case the heat would not be given out sufficiently.

Far too little attention is paid to the applicability of sawdust for giving a loose texture to dense materials, and lightening heavy ones. Thus the well-known Laming's mixture employed for the purification of illuminating gas in gas works would be far too dense by itself, and must therefore be mixed with a large quantity of sawdust to give it a coarse, open texture. Both sawdust and wood-shavings may be used for the purification of coal gas if they are soaked in a solution of copper sulphate and the gas then passed over them. Mariot and Sugden proceed as follows: Instead of purifying coal gas from ammonia by passing it through sulphuric acid, it may be passed through vessels resembling dry lime purifiers, namely, boxes containing hurdles on which a loose material containing sulphuric acid is spread out. Sulphuric acid of 1·425 specific gravity is the most suitable for this purpose. This sulphuric acid is mixed with sawdust in the proportion

of 84 parts of the acid to 50 of sawdust. The mixture is then heated to about 120° C., so that the sawdust becomes carbonised and the charcoal absorbs the acid. This yields a dry, porous material, which, when spread upon hurdles, allows the gas to pass readily. In charging the purifiers a layer of old material, already saturated with ammonia, is placed first on the hurdles in order that they may not be acted on by the acid, and the fresh mixture is then placed on this.

Croll employs for the purification of coal gas the residue of manganous chloride from the chlorine stills, which he mixes with lime and sawdust, and exposes to the gas until it contains 30 to 40 per cent. of ammonium chloride, which can then be recovered by lixiviation or sublimation.

In the cementation process of making steel, the iron bars are packed with sawdust into an iron box, which is then closed with a clay luting and moderately heated for a longer or shorter time, according to the thickness of the bars. The steel obtained is melted in a closed plumbago crucible under a layer of fresh sawdust, and may be poured into heated iron moulds.

The acetates of potassium and sodium are said by Sonstadt to be producible from the sulphides of the two metals by evaporating their solutions to dryness with sawdust and carbonising the mixture below a red-heat. The black mass is boiled down to dryness with milk of lime until a sample of the liquid is found, after filtration, to be free from sulphur. The whole quantity is then filtered, the filtrate evaporated to dryness and the residue gently roasted. The product is a tolerably pure acetate.

Mortar made with sawdust has repeatedly been advocated as a means of getting rid of moisture from damp walls. This mortar is prepared in the following manner : Ordinary slaked lime is thinned with water ; sawdust is at once mixed with the lime, instead of sand, using such a proportion that the lime still retains the necessary binding power.

A solution of water-glass may also be added to this mixture. Such mortar is not only recommended for the building of new walls, but also for plastering existing walls, and is said to be especially suitable for stucco, so that whole façades may be constructed of it. A very good roofing material may be produced by mixing melted coal-tar, flowers of sulphur, finely powdered hydraulic lime, and sawdust, and pouring the plastic material into moulds or rolling it out into slabs.

Mortelette has recommended sawdust for the prevention of boiler scale; the mixture employed consists of sawdust, soda, pine-wood charcoal, rye meal and clay.

Dyes are manufactured by Croissant and Bretonniere from sawdust. The process consists in the removal of hydrogen from the wood by the action of sulphur at a high temperature. The products are called by their discoverers "organic sulphides," in which hydrogen is replaced by sulphur. These sulphides oxidise when exposed to the air, and give off sulphuretted hydrogen when treated with acids.

The manufacture of these dyes from sawdust is simple, requires no complicated apparatus, and little labour; they are cheaper and more permanent than those most commonly in use; a kilogram of dye from sawdust, for example, costing only about half as much as the same quantity of logwood extract, and possessing four times the dyeing power.

The property which sawdust possesses of absorbing water is often utilised in public conveyances, omnibuses, tram-cars, etc., to keep the floor free from wet; sawdust is strewn on pavements in frosty weather to prevent slipping, and serves as a safeguard against accidents.

Sawdust may be used as a mild cleaning powder for tarnished silver, and beech sawdust as a polishing powder for gold. Sawdust may also serve as a kind of soap for the cleansing of house linen, since friction with it is very efficacious for removing the dirt.

The Smith Consolidation Company in Argo undertake the conversion not only of small coal, but of sawdust shavings, cotton-wool fibres, etc., into briquettes, in order to utilise these substances as fuel. In the machine employed for this purpose a triple mould revolves round a vertical axis, and is so arranged that when one of the moulds is under the charging funnel, the second is under the compressing stamp, and the third is being emptied by another stamp. The machine is capable of converting 1500 kilos ($1\frac{1}{2}$ tons) of the sawdust of Weymouth pine-wood into blocks per hour. This process, the manufacture of briquettes from wood-waste, has in quite recent times made very great progress, both sawdust and wood-shavings being compressed, either with or without binding materials into hard masses which either serve directly as fuel, or are carbonised in closed vessels for the recovery of the products of distillation.

For the preparation of wood-pulp (according to Reth) the sawdust is disintegrated by an edge runner working in a stone bed; the material thrown out at one side is immediately replaced at the other until it has the desired degree of fineness. The edge runner is arranged exactly like the beating roller of a paper-mill.

For the manufacture of short-fibred cellulose, sawdust may be treated by the soda, or sulphite processes.

F. W. Wendenburg prepares wood-meal fodder in the following manner: The wood (sawdust) is ground to a fine meal, to 50 parts of which there is then added $1\frac{1}{2}$ parts of rock-salt, and enough hot distiller's wash mixed with $\frac{1}{1}$ part of hydrochloric acid to form a thin pulp. After boiling for two hours this is ready for use as fodder, but it may also be dried and pressed into moulds, or can be baked in the form of dough.

Sawdust finds extensive employment in all the metal industries, especially for drying articles which have been treated with acids, no other substance being so effective as

sawdust in drying and cleaning the objects and preventing subsequent oxidation (rust), or verdigris formation. Articles made of horn, ivory, tortoise-shell, and bleached bone cannot be better dried than in sawdust, since they then neither crack nor warp. For polishing metallic wares sawdust may be used with the greatest advantage; the articles to be polished being placed, together with a large quantity of sawdust, in rotating drums, and acquire their polish from the friction of the sawdust. The sawdust for this purpose must be perfectly dry.

A very useful product can be obtained by mixing sawdust and refuse wood-chips with the residues from the manufacture of turpentine and rosin, and pressing the mixture into moulds; it is used for kindling fires. The same waste materials have also quite recently been utilised in considerable quantities for the manufacture of carborundum and of calcium carbide.

A method of utilisation which will assume very large dimensions in the future, and which is perhaps even destined to produce a scarcity of sawdust, is the conversion of that substance into sugar and alcohol, now that the difficulties encountered in carrying out on the large scale the processes elaborated on the small scale have been overcome.

There are, without doubt, still other methods of making use of sawdust, some of which are of secondary importance, whilst others have not been made public, and it is probable that in the future still more uses will be found for this material.

Most of the methods of utilisation which have been mentioned above may be applied to extracted dye-woods, etc., and in some cases, where large amounts of these waste materials are available, they may be re-extracted, and then utilised as fuel to evaporate the very weak decoction so obtained, for which purpose ordinary fuel would be too costly.

A similar product, to which hitherto far too little attention

has been directed, is tan (oak bark), the complete utilisation of which in tanneries is not possible with the primitive methods of extraction generally employed, and which therefore still contains a considerable amount of tannin, which by processes similar to that mentioned above can nevertheless be wholly extracted. A process has lately been adopted in France, analogous to Schutzenbach's method of extracting sugar from beet-root, which extracts all the tannin from oak bark in a perfect manner, the method of working being as follows: A large number of round tubs, about 2 metres (6½ feet) deep and 1¼ metre (4 feet) in diameter, in each of which a second perforated bottom is placed 1 decimetre (4 inches) above the floor, are connected by pipes, each of which is inserted at one end under the false bottom of one tub and at the other 0·15 metre (6 inches) below the edge of the next tub. The tubs are filled with the bark, and water is run into one of them; the extract passes on to the second, third, and fourth, etc., becoming stronger in its progress, and extracting less and less tannin from the charge in each succeeding tub. The strong solution is finally drawn off from the bottom of the last tub. Supposing 10 tubs to be in use, the bark in the first tub will have been extracted 10 times when that in the last tub has only been extracted once. When 10 tubs of water have been run upon the charge in the first tub that charge will have been completely exhausted. The last water is drawn off, and the spent tan thrown out. The tub is refilled with fresh bark and is then made the last of the series. In the same way each charge as it becomes exhausted is replaced by fresh bark, and the process goes on continuously. This process not only exhausts the bark completely, but furnishes the tanner with extracts of varying degrees of concentration.

Extracted bark and other tanning materials may further be employed for the manufacture of ink. The spent tan in this case is treated with caustic soda and the filtered

liquor is mixed with green vitriol (ferrous sulphate) and exposed to the air. Spent tan may be very advantageously used as a fuel if it is mixed with a little nitrate of lead, made into briquettes with lime, and dried; such fuel is said to be especially suitable for heating railway carriages.[1]

A considerable quantity of spent tan is used for spreading on riding roads and in equestrian circuses; it is used in agriculture partly as a manure, partly for forming hot beds and keeping up the warmth of greenhouses. A certain amount is used in pleasure gardens. Flower-beds which contain tan mixed with the earth remain free from weeds, the soil is kept in a loose condition, in the dryest season remains damp without any need of watering, and is altogether free from the larvæ of the cockchafer. The growth of the trees is vigorous, the branches are given off at short intervals, and both leaf and fruit-bud formation are strong. Root production is also greatly augmented. Old trees growing in a tan soil are particularly fruitful and produce handsome fruit; standards exhibit the same result. By using spent tan not only is the cost of weeding saved, but the roots are preserved from the attack of insects, growth and fruit formation are promoted, and therefore profit is increased.

When we come to consider more closely the methods by which sawdust, waste wood in larger or smaller fragments, extracted dye-woods, spent tan bark, nut-galls, etc., can be utilised, we find that the processes may be divided into two main groups, one of which may be called the chemical, and the other the mechanical application. The chemical processes comprehend :—

1. Employment as fuel.
2. Dry distillation.
3. Treatment with various chemical reagents, for the

[1] In Germany the passenger carriages are frequently warmed by stoves.—(*Trans.*)

production of cellulose, vinegar, alcohol, sugar, gum, oxali acid.

The mechanical processes, which, however, must no in all cases be regarded as strictly mechanical, since man of them involve chemical changes, embrace :—

1. The production of artificial wood.
2. Employment in the manufacture of explosives.
3. Use as a means of producing porosity and lightness.
4. The manufacture of manure.
5. A variety of other methods of utilisation.

For the study of the mechanical processes a knowledg of the chemical constitution of wood is not necessary; o the other hand, such knowledge, as well as an acquaintanc with the changes which occur when wood is exposed t a high temperature, or treated with reagents, is indis pensable in considering the chemical processes, and t these points we will here devote a few words.

Wood, chemically considered, consists of a number c different substances, the nature and proportions of whic are dependent on the kind and the age of the plant fro which it is derived. Broadly, we may distinguish in a varieties of wood two constituents, the woody fibres an the sap, the latter again consisting of water and the sub stances held in solution. The woody fibres consist of cellu lose or cell-substance, which forms elongated cells groupe into bundles, and of lignin or the incrusting material.

Cellulose $(C_6H_{10}O_5)_n$ belongs to the class of carbohydrate To prepare it from wood, the wood must be treated wit ether, alcohol, acids, and alkalis, and finally be copiousl washed with water. Pure cellulose has the same compos tion as starch, and in many of its chemical relationshi exhibits a similar behaviour, but the one substance ha never yet been converted into the other, although fro either it is possible to prepare a fermentable sugar, fro which alcohol can be obtained.

Experiments in this direction have indeed been attende

with the result expected on theoretical grounds, but on the large scale, in consequence of the carbonisation of much of the woody substance and the large consumption of sulphuric acid needed, the process presents great difficulties. The action of hydrochloric acid on cellulose produces hydrocellulose and sugar (wood-sugar or xylose); nitric acid forms nitro-celluloses; cellulose melted with caustic alkalis yields compounds of oxalic acid. When cellulose is burnt with free access of air it leaves an ash; if heated with exclusion of air it yields some members of the fatty acid series, also wood alcohol tar and charcoal.

Wood-sap, besides water and mineral constituents, contains a variety of soluble substances, such as the carbohydrates (sugar, gum), albuminoids, and pectous substances; also in individual species of plants, characteristic colouring matters, tannins, other extractive substances and resin also occur.

When wood is burnt with free access of air, gases are produced, whilst a certain amount of heat is developed, and an ash is left which contains the mineral constituents of the wood, the carbonates of potassium and of sodium, carbonate and sulphate of calcium, magnesia, phosphates, etc. In localities where timber is abundant, carbonate of potassium (potash) may be manufactured from wood-ash.

If, on the contrary, wood is burnt with restricted access of air, or is heated in vessels from which air is excluded, which is the case when it is burnt in charcoal heaps, or heated in retorts, it undergoes a more or less complete dry distillation, other products being obtained.

The dry distillation of wood commences at a temperature of 100° to 130° C., the first substance to distil over being water, the proportion of which naturally depends on the degree of dampness of the wood. The dampness of wood-waste will largely depend upon whether it has been kept under cover or been left lying in the open, and this will materially influence the amount of fuel necessary for its

distillation. It is therefore advisable, where it is practicabl to subject sawdust to a preliminary drying before it i introduced into the distilling apparatus. As the tempera ture is raised from 145° to 500° C. the products which pas over are water, acetic acid, wood-spirit (methyl alcohol) and tar, as well as various gases, whilst wood-charcoal is lef in the retort. When the temperature is rapidly raise acetic acid is the chief product; this must, however, b quickly removed from the heated vessel, or it will underg further decomposition.

The products of the distillation of wood vary both i kind and in amount according to the degree of heat t which it is exposed. The higher the temperature th greater is the proportion of gaseous products, therefor it is usual not to exceed an incipient red-heat.

With regard to the process of distillation itself, tw different modes of operating must be distinguished :—

1. The wood (sawdust and other refuse) is submitted t distillation with the object of obtaining the largest possibl yield of acetic acid and tar, with which end in view th distillation is carried on slowly and at a low temperature even in this case a considerable amount of gas is produced which, however, for the most part consists of carbon dioxid and carbon monoxide, burns with a very feebly luminou flame, and can best be utilised for the production of hea by passing it first through a layer of incandescent carbon by which the carbon dioxide is reduced to monoxide. Thi reduction takes place in those forms of furnace in which the gases from the distillation are conducted into the spac below the fire-grate.

2. The wood is distilled with the intention of obtainin gas and tar, with but little acetic acid; in this case it i rapidly raised to a very high temperature; the greater par of the volatile products, consisting as they do of carbon hydrogen, and oxygen are further decomposed in the retor with formation of hydrocarbons, which are partly liqui

and partly gaseous. The gases so obtained have a higher illuminating power; whilst the yield of tar is considerable and that of acetic acid small.

The pyroligneous acid resulting from the distillation is a mixture of methyl alcohol, methyl acetate, acetone, acetic acid, furfural and water; the tar contains benzene, toluene, xylene, cumene, naphthalene, paraffin, phenol, cresol, etc.

According to the temperature the products are :—

(*a*) Gases from 160° to 360°: carbon dioxide (carbonic acid), carbon monoxide, marsh gas (methane): from 360° to 432°: hydrogen, acetylene, propylene, butylene.

(*b*) Pyroligneous acid from 180° to 300°: formic and acetic acids; from 200° to 360°: propionic acid, butyric acid, valeric acid, caproic acid, methyl alcohol; from 250° to 360°: acetone, metacetone, methyl acetate, methylamine acetate, and aldehyde.

(*c*) Tar from 360° to a red-heat.

The charcoal, acetic acid and methyl alcohol obtained by the distillation of sawdust have hitherto been regarded as the principal products, the tar being regarded as a by-product, and the process of distillation conducted accordingly. Lately, however, more attention has been paid to the tar, and from it have been obtained benzene, toluene, and naphthalene, hydrocarbons which are extensively employed in the manufacture of artificial (or so-called "aniline") dyes. In carrying out a distillation it is therefore necessary, in the first place, to decide what principal products it is desired to obtain, and to arrange accordingly. To give further details respecting the products of distillation would carry us beyond the limits of this book, which is intended to deal only with the utilisation of wood-waste; the reader may be referred to the following special treatises on this subject: *Das Holz und seine Destillations producte* (Wood and its Products of Distillation), by Dr. George Thenius; *Die Verwerthung des Holzes auf chemischem Wege*

(The Utilisation of Wood by Chemical Methods), by Dr. Jos. Bersh (2nd edition); and *Die Fabrikation der Anilinfarbstoffe* (The Manufacture of the Aniline Dyes), by the same (published by A. Hartleben).

Altogether different are the products obtained when wood is acted on by chemical reagents. We have already seen that wood consists of two principal substances, cellulose and lignin, or the incrusting substance. By suitable treatment, boiling with nitric, sulphuric, or hydrochloric acid, with caustic soda, with sulphurous acid, and with sulphites under pressure, the cellulose may be obtained more or less pure, the incrusting substances being dissolved out. In the decoctions there exist numerous gummy and saccharine substances, and many attempts have been made to bring these into use.

By boiling or heating with dilute hydrochloric acid the cell walls of the wood become broken down, the incrusting substance is dissolved and converted into grape-sugar (glucose), whilst a substance called fibro-cellulose or lignose is left, which is more easily attacked and dissolved by alkalis than cellulose. The following are the results of some experiments in this direction.

In order to combine the production of grape-sugar and alcohol with that of wood-fibre, the first step was to ascertain the best proportion of acid to wood, and the most suitable concentration, in order to obtain a maximum quantity of sugar with a minimum quantity of acid. The following experiments were made with this object :—

A. Two hundred grams of sawdust (pine-wood with 15 per cent. of hygroscopic moisture) were boiled for 1 to 2 hours with 2 litres of hydrochloric acid of 5° Bé. = 1·04 specific gravity, corresponding to 162·2 grams of HCl. The sawdust, which acquired a reddish-brown colour, was thoroughly washed, the liquid neutralised with soda and mixed with lead acetate. An estimation with Fehling's solution showed the presence of 18·12 parts calculated as

grape-sugar (glucose) per 100 parts of wood taken. It must be remembered, however, that xylose from wood-gum is also present. The greyish-brown lignose dried at 100°, weighed 129 grams, corresponding to 64·5 per cent. of the wood taken. Erdmann ascribes for lignose the formula $C_{18}H_{26}O_{11}$, and gives the following equation for its formation from cellulose :—

$$C_{30}H_{46}O_{21} + 2H_2O = C_{18}H_{26}O_{11} + 2C_6H_{12}O_6,$$

according to which pure cellulose should yield 56·23 per cent. of lignose.

B. One hundred grams of sawdust similarly treated with 1 litre of cold hydrochloric acid of 10° Bé. (= 1·075 sp. gr. or 150 grams of HCl) gave 25 per cent. of sugars calculated as glucose and 51·6 per cent. of lignose. The colour of the lignose in the wet state resembled that of rotten oak; in the dry state it was reddish-brown. When washed with dilute soda solution the washings were dark brown, which is not the case with ordinary wood-fibre. When thus treated the soda solution penetrates into the cells in which hydrochloric acid is present. An evolution of carbonic acid gas takes place, which has a disruptive action on the fibres, and would perhaps serve as a preparation for their subsequent employment.

C. One hundred and eighty grams of sawdust with 800 c.cm. of hydrochloric acid of 6·5° Bé. (= 1·048 sp. gr., or 76·8 grams of HCl), boiled for several hours, gave 20·83 per cent. of sugar calculated as glucose and 62·22 per cent. of lignose.

Two experiments with fine oak sawdust (6·5 per cent. of moisture) gave :—

Per cent. of sugar calculated as glucose.	Per cent. of lignose.
13·22	62·75
15·43	66·11

The results of the three experiments with pine-wood were as follows :—

	HCl used per 100 parts of wood.	Sugar calculated as glucose obtained per 100 parts of wood.	Sugar calculated as glucose obtained per 100 parts of HCl.
1	81·1	18·12	22·37
2	150·0	25·00	16·66
3	42·6	20·83	48·89

It is said that these proportions are already employed in practice, and that after the acid solution of the sugar has been neutralised with lime down to 0·5° of Ludersdorf's acid scale, a fermentation of the mixture for 24 hours followed by distillation gives from 450 kilos. (9 cwt.) of sawdust, 26·5 litres (5·8 gallons) of 50 per cent. alcohol, free from any turpentine odour and of agreeable flavour.

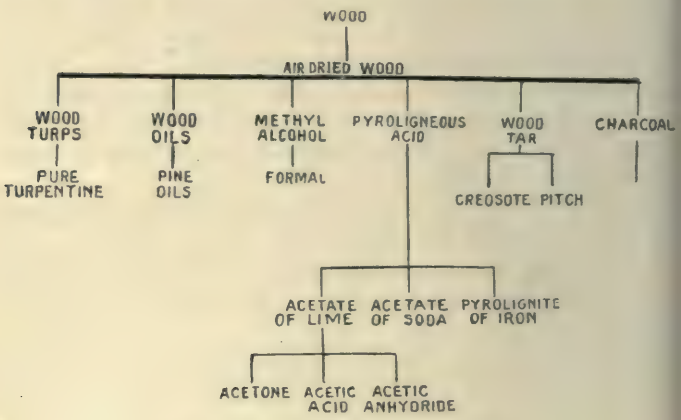

Chart of Wood Distillation Products.

CHAPTER II

THE EMPLOYMENT OF SAWDUST AS FUEL WITH AND WITHOUT THE SIMULTANEOUS RECOVERY OF CHARCOAL AND THE PRODUCTS OF DISTILLATION

THE proportion of combustible matter in sawdust, and the calorific effect obtainable from its combustion, are exactly the same as those of the wood from which it was derived, since sawdust is no more or less than wood-fibre very finely subdivided by artificial means. But sawdust, when used as fuel, has the property of forming a layer which is very impervious to air, of falling through the fire-grate in consequence of the fineness of its particles, and of giving off a large amount of water-vapour which impedes vigorous combustion. The compression of the heap of material prevents the due access of air, the layer of sawdust becomes carbonised at the surface, and finally the heap becomes covered with ash to such an extent that combustion is completely arrested unless the heap is continually turned over. When using sawdust for heating purposes the only object is to utilise its calorific power. If the sawdust is made up with peat, tan-refuse, coal slack, etc., into briquettes and thrown in this form upon the fire-grate, its combustible matter can be more efficiently utilised than by trying to burn it in its loose condition. The conversion of the sawdust into solid blocks nevertheless renders it more expensive, and it is also difficult to find a completely suitable binding material, which will aid rather than impede the combustion, unless the substance is compacted by employing an exceedingly high pressure instead of using a binding material.

The binding material must be so selected that it not only holds the sawdust together during transport, loading, and unloading, but possesses sufficient resistance to heat to prevent the briquettes from falling to pieces during combustion, and thus reproducing a bed of fuel impervious to air. Up to the present time very little practical use has been made of these compacted sawdust briquettes; attention having been for the most part directed to devising forms of furnace which will burn the loose sawdust direct. A better mode of utilising sawdust as fuel is to mix the dry sawdust with $\frac{1}{6}$ of its weight of coal; at the same time it is of especial importance in using this material to take care to have a vigorous coal fire as a basis on which the sawdust can be thrown. With such a coal fire for a basis the following advantages are obtained: (1) The evaporation of the water in the sawdust, the proportion of which useless constituent may vary from 25 to 40 per cent., is much accelerated; (2) the combustible gases are more rapidly evolved and burn with a flame, whilst the carbon, being converted into carbon dioxide and not into carbon monoxide, gives a greater heating effect.

A new process for converting sawdust into briquettes aims at heating the substance so far that the rosin naturally contained in the wood is softened, and then, without any added binding material, pressing into moulds at very high pressure. A fuel prepared in this manner is easily transportable, has an essentially higher heating power than brown coal, and is equally suitable for household and for technical use.

It is obvious that for the advantageous employment of sawdust in its natural state as a fuel the first consideration is to give an appropriate form to the fire-grate. The sawdust is generally thrown on the grate in a somewhat thick layer, and the spaces between the fire-bars, which serve as channels for the supply of air, are to a great extent choked by it. But since combustion without a sufficient supply

of air is quite impossible, it is obvious that the grate must in all patterns of furnace be so constructed that there shall be no deficiency of oxygen. The proportional area of the fire-grate must be adapted to the nature of the fuel to be burnt on it, for a very different area will be required for burning, on the one hand, good coal, and, on the other hand, sawdust; the correct proportion must therefore be adapted to the amount of steam which it is required to raise.

No special difficulties, either in the construction of the grate or the furnace, are required to be overcome if only small amounts of sawdust have to be burnt in combination with other fuels; in that case nothing further is necessary than from time to time to throw upon the coal fire when it is in a vigorous state of combustion a few shovelfuls of the well-dried sawdust, and let it burn without disturbance, an operation which can easily be brought into practice in places where exhausted dye-wood, tan, etc., are produced as refuse in amounts which it is easy to dispose of. The matter is, however, quite different when it is necessary to burn sawdust either entirely, or almost entirely, alone.

With this end in view a considerable number of furnaces for burning sawdust have in the course of time been invented, the chief of which will be here more minutely described and elucidated by figures. These are the Kraft sawdust furnace, the Lundin furnace, Koch's sawdust furnace, Walter's furnace for making wood tar, the Andre furnace for sawdust, the arrangement of Niederberger & Co. for burning damp wood-refuse and sawdust, Godillot's pyramidal grate for pulverulent fuel, gas generators and condensers for sawdust, and the Zwillinger apparatus for carbonising sawdust, as well as a number of newer patterns which will also be minutely considered. These designs are exceedingly various in principle; they may nevertheless be easily divided into two groups :—

1. Patterns which are designed entirely with the object of burning the sawdust for heating purposes, and in which

therefore no value is attached to the condensation of volatile products derived from the wood.

2. Patterns which are chiefly designed to accomplish the latter object, and with which, besides tar, wood-spirit, acetic acid, acetone, etc., a serviceable charcoal is also to be obtained. In furnaces of the second class it is especially to be recommended that the gas resulting from the distillation should be conducted into the fire. The apparatus of Niederberger & Co. allows the employment of damp material, so that such substances need not be dried first, which would otherwise require at least space and labour for turning the material over, even if no special drying arrangement was necessary. Godillot's pyramidal fire-grate also allows damp material to be employed. Zwillinger's furnace is constructed on very ingenious principles: the sawdust and other wood-refuse are not burnt directly, but are carbonised in closed vessels, so that all the volatile products of the dry distillation of the wood can be condensed, and the gases used either for lighting the works or for heating purposes, thus utilising very completely this waste material, which is in the highest degree advantageous in localities where much timber is felled and cut up. In fact Zwillinger's furnace has already proved practically successful in several places, especially in Galicia and Silesia, the tar and pyroligneous acid being either worked up on the spot or sent to chemical works. Weiss and Guttler have proposed to carry out the decomposition of the wood in an atmosphere of heated gases, heating the retorts from outside. Waisbein devised a plan of decomposing sawdust in an atmosphere of producer-gas, whilst Guttler designed an apparatus for the preparation of powdered charcoal, in which the external heating of the retorts was dispensed with. A. Gustav, as a means of carbonising wood or wood-refuse, introduces the material into tubes or channels and heats it under pressure, whilst allowing the evolved gases to escape gradually, so that a continuous solid carbon rod is formed which retains

its coherence after removal from the tube or channel. G. Scheffer has constructed a special furnace from ordinary bricks, in which wood-refuse of all kinds, such as spent tan, sawdust, etc., is submitted to dry distillation by the partial incomplete combustion of the substances themselves. In trials carried out on the large scale with tan containing 24 per cent. of water, complete combustion was effected. The vapours evolved from the furnace pass first through acetic acid saturated with lime, and then rise through a coke tower through which milk of lime is allowed to flow. The gases which escape finally are either burnt in the same way as producer-gas when there are several furnaces, or are allowed to escape into the chimney. Where there is no chimney shaft the necessary draught for the distillation furnaces is produced by the hot air from a special furnace in communication with them. F. Frisch of Niederweise in Saxony likewise manufactures pyroligneous acid from spent tan, etc. Readfield and Halliday work up sawdust, and obtain a result which does not in any way agree with the statement in chemical treatises that resinous woods yield proportionately little acid. Eight retorts of 45 cm. diameter (18 inches) produce in 24 hours as much pyroligneous acid as 16 simple retorts of 1 metre (39¼ inches) diameter. The wood-charcoal which is produced from the sawdust is employed in large amounts for the manufacture of artificial manure, and possesses in a high degree the property of deodorising the urine used in dye works, furnishing therefore an easy means of getting rid of the disagreeable odour which escapes from the urine tanks.

Kraft's Sawdust Furnace.—This furnace is shown in Figs. 1 to 3; Fig. 1 showing a longitudinal section through the middle, Fig. 2 a transverse section, and Fig. 3 a horizontal section. The apparatus consists of retaining walls, A, B, of any desired form, the simplest being an elongated quadrilateral, which is also that most easily constructed. The wall B is usually already existent, being that of the steam

boiler or furnace hearth. The fuel is introduced from above through the opening C, which is covered by a sheet-iron cover as soon as the workman ceases to poke. The lifting of this cover is assisted by a counterbalance. At the level, a, b, the fireplace is widened out by the walls A and B being recessed The lower part of the apparatus forms an ash-pit,

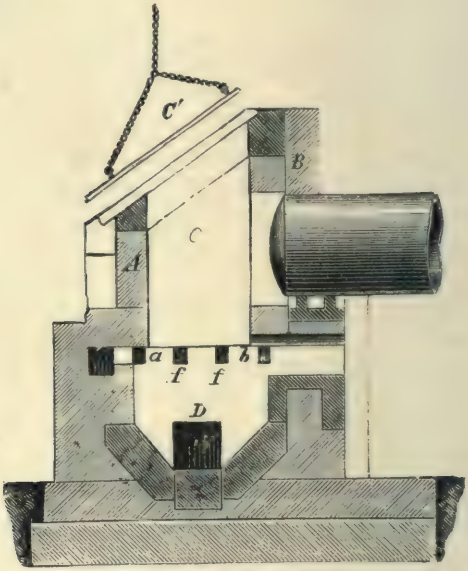

FIG. 1.—Kraft's Sawdust Furnace (Longitudinal Section).

and is furnished with two openings, D, which can be closed by tile or sheet-iron ash-pit doors. These openings are closed during the working of the apparatus, being only opened for the removal of ashes or slag. Each of the ash-pit doors may have a small opening in it through which air can be allowed to enter if for any reason the combustion requires to be invigorated. In the front part of the apparatus there is a channel, E, which passes through the whole

length of the brickwork, being closed at both ends by wooden or iron discs. This channel communicates with the combustion chamber by a number of pigeon-holes, f, f, by which a supply of air is introduced. The combustion takes place in the lower part of the apparatus, the gaseous products of combustion passing through the opening below the boiler or through the working hearth. The fuel burns therefore between the openings f and g. It often happens that

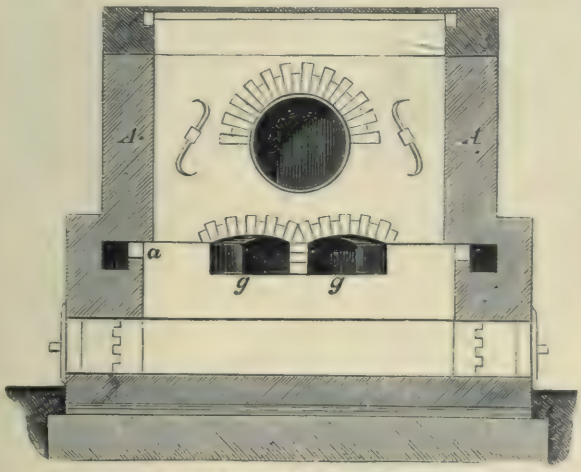

FIG. 2.—Kraft's Sawdust Furnace (Cross Section).

arches form in the heap of sawdust, in which case the whole concave surface of the arch is in a glowing state; small fragments of the burning matter detach themselves from the lower surface of the arch, fall to the floor and burn in the ash-pit.

As it frequently happens that these arches collapse, the combustion would thereby be arrested or hindered if it were not for the recesses a and b, which keep the operation going. If the air is prevented by the collapse of an arch from passing directly from *f* to *g*, it takes a circular course round the

apparatus, continuing in its course the combustion of the material. A lofty chimney, or a fan, produces a sufficient draught for this purpose, so that in a few minutes the combustion reattains its original intensity. The walls of the furnace must, in fact, be of such a height that the falling in of such an arch does not uncover the channels *g*, *g*. The action of the furnace is a continuous one; the new fuel added taking fire and burning readily, because the lower walls are very hot and radiate heat from all sides. The

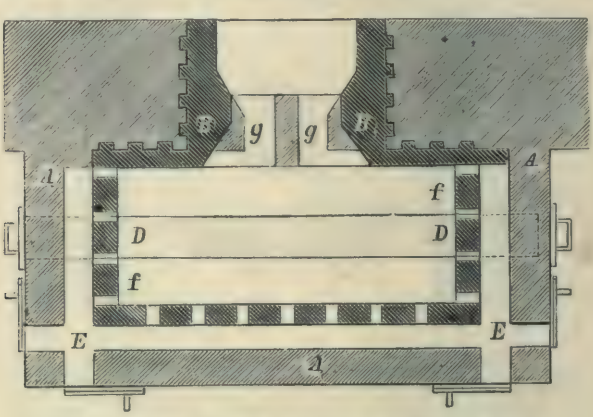

FIG. 3.—Kraft's Sawdust Furnace (Horizontal Section).

combustion is also a complete one, since the openings *f*, *f* produce a very intimate admixture of combustible gases with atmospheric air at a high temperature. Together with the finely divided fuel (sawdust), larger fragments of the same may be burnt. Thus, in a trial made at a paper-mill, wood billets were burnt along with the sawdust with as good results as with sawdust alone.

After a short time the fire-bricks which line the channels *g*, *g*, become white hot, and if dry sawdust is being used the temperature rises to a point which is sufficient for any furnace operation.

The work of this furnace is continuous and is easily regulated; it will burn the very poorest kinds of fuel, such as rotten tree-trunks, pine needles, etc., whilst its erection is economical, and, as the following experiments show, it appears to present very great advantages. In an experiment on raising steam in a steam boiler, the combustible material consisted of sawdust and shavings, the former being composed of $\frac{1}{3}$ pine, $\frac{2}{3}$ oak, the latter $\frac{1}{2}$ oak, $\frac{1}{4}$ pine and $\frac{1}{4}$ poplar. The trial lasted 15 hours. The fuel burnt amounted to 1544 kilos of sawdust and 718 kilos of shavings, or a total of 2262 kilos. The quantity of water evaporated amounted to 3680 litres. The temperature of the feed water was 18° C., and the tension of the steam produced was 4·95, or practically 5 atmospheres (75 lb. per square inch). The substances burnt as fuel contained 38·6 and 27 per cent. of water respectively. The fuel lost therefore 790 kilos of water. Assuming that the heat required to evaporate this quantity of water in the furnace would have evaporated an equal quantity in the boiler, we may take it that $2262 - 790 = 1472$ kilos of combustible matter evaporated $3680 + 790 = 4470$ kilos of water, or 3·04 parts of water for 1 part of combustible material.

Another experiment with an 8 to 10 horse-power steam boiler gave the following result: The substances to be burnt were merely air-dry, and consisted of 413 kilos of pine bark, 154 kilos of oak sawdust, 18 kilos of oak shavings, and 152 kilos of oak waste, or in all 717 kilos. The engine ran for 10 hours and drove 2 water pumps, 3 circular saws, 2 planing machines, and 2 drilling machines. The boiler was fed with water at 20° C., and a steam pressure of 75 lb. was maintained. Although this experiment is an incomplete one, it sufficiently demonstrates the value of the apparatus.

André's Furnace for Sawdust.—This furnace is a modification of that of Kraft, differing from the latter in having the abrupt widening of the combustion chamber replaced

by one which increases gradually from above downwards, and also by the introduction of some structures of prismatic form, built of fire-bricks, into the lower part of the combustion chamber. In Fig. 4, A, B represents the front of the boiler which is to be heated. The material to be burnt is introduced from above into the chamber C, D, falling on the

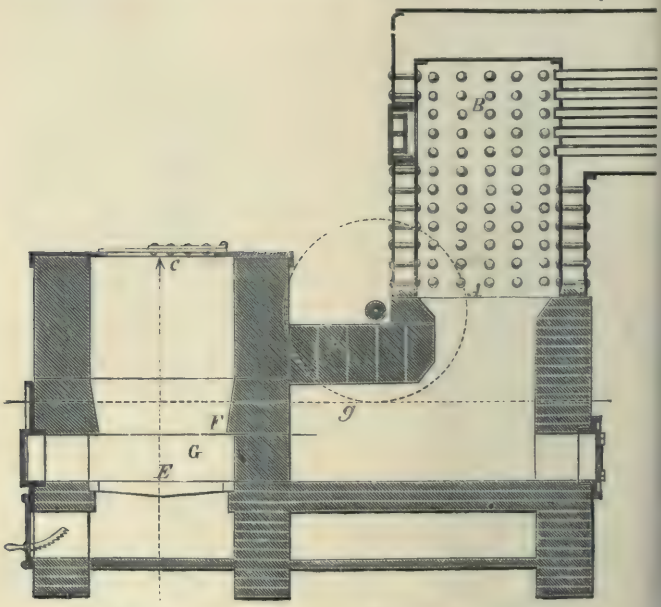

FIG. 4.—André's Sawdust Furnace (Section).

prismatic blocks, F, F, situated above the fire-grate, E, which may be replaced by a small arch. The principal combustion takes place in the chamber G with the air which enters from below the fire-grate. With ordinary boilers this chamber G can be dispensed with.

The following experiments on the efficiency of this furnace have been made :—

1. Spent tan burnt in 12 hours, 1420 kilos; this had for several weeks been kept on the top of the boiler and was thoroughly dry. Water evaporated 1·85 kilos per kilo of tan; temperature of the gases at throat of chimney, 256° C.

2. Material consumed in the course of 12 hours, 340 kilos of tan, and 1025 kilos of sawdust. Water evaporated 1·29 kilos per kilo of fuel; temperature of gases. 250° C

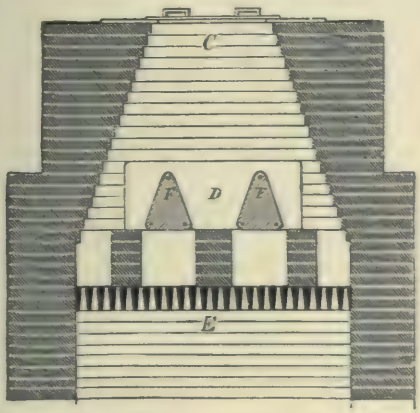

Fig. 5.—André's Sawdust Furnace (Cross Section through Combustion Chamber).

3. Material burnt in 12 hours, 414 kilos of coal. Water evaporated, 4·54 kilos per kilo of coal: temperature of gases, 250° C.

Koch's Sawdust Furnace—Koch's sawdust furnace is simple in construction, and although used in tanneries for burning spent tan as fuel, it may also be employed for sawdust and peat. The problem to be solved was the combustion of a wet pulverulent or granular material without previous drying or agglomeration, and also without having to force the air through the fire-grate by mechanical means. Spent tan is a substance of this character; it is thrown out

of the tan-pits saturated with water and in such a finely divided condition that it resembles sponge, rarely containing granular fragments as large as a pea. In this condition it would be impossible to burn it on an ordinary grate without previous drying in the air, which would require considerable space.

In one particular case this apparatus was employed for heating steam boilers, and the tan, although pressed, contained 40 per cent. of water.

The furnace consists essentially of a rectangular pit about 5¼ feet long, 40 inches wide, and 4 feet deep, the bottom of which contains two fire-grates 18 and 20 inches wide and 40 inches long. The front wall of the fireplace has two doors for cleaning the grate, and two flues for carrying off the products of combustion. Two arches are thrown across the combustion chamber about 12 inches above the fire-bars, leaving openings at the sides 8 to 12 inches wide between the arches and the walls of the chamber for the descent of the fuel. The upper surface of these arches is roof-shaped, the ridge running parallel with the fire-bars. Iron bars are also stretched across the chamber, to obstruct the fall of the fuel, thus preventing it from settling down in a dense mass. The wet tan, thrown into the furnace, falls first on the upper surface of the arches, where it dries as it slides down towards the sides, and having passed through the side openings, it is delivered on to the fire-grate in a perfectly dry condition. It there forms a layer 3 to 4 inches thick, which burns freely. There is no necessity for keeping a cover on the combustion chamber whilst the furnace is in use, but when work ceases in the evening the top is closed by cast-iron plates, the damper in the chimney, fire-doors, and ash-pit being likewise closed. By this means a dull red heat is maintained during the night, so that when fresh fuel is added combustion recommences immediately. In cases where the substance to be burnt contains other volatile products than water, the ash-

pit may be closed and the air for the combustion is then caused to pass through the mass of fuel from above downwards. In this case, however, the water-vapour which is drawn into the flues with the products of combustion reduces the heating effect considerably, and, before making any alteration in the original arrangement, it is desirable to consider which is the better mode of burning a material containing a determined proportion of moisture.

Sawdust and Tan Furnaces.—The furnaces shown in

Fig. 6.—Furnace for Burning Sawdust or Tan for Heating a Cornish Boiler.

Figs. 6 and 7 are intended for dye-woods, tan, and sawdust. If the wet materials are well pressed before use they can in most cases be employed as the sole fuel, without any admixture of coal.

Fig. 6 shows the fireplace of a Cornish boiler; the grate rising at both sides to meet the channels for the descent of the fuel. These channels widen out to large hoppers, which can be closed by a cover.

The fuel is charged into the hoppers and is conducted to the grate through the side channels, for which purpose doors are constructed in the front wall of the fire-chamber.

Fig. 7 shows a similar construction for a Lancashire boiler. In this case the fire-grate is divided by a partition wall which serves both to strengthen the structure and to regulate the distribution of the fuel over the grate area, which in this case is wider. These furnaces are adapted either to steam boilers with internal flues, or to boilers which are heated externally. In the latter case the fire-place must extend 5 to 6½ feet in front of the boiler.

Fig. 7.—Furnace for Burning Sawdust or Tan for Heating a Lancashire Boiler.

The furnace shown in Fig. 8 is fitted with a step grate, such as is used in large works where a number of boilers are arranged side by side. The fuel is brought in trucks running on tram lines, and is shot from these into a hopper, from which it can be brought down to the grate by a rake.

This method of feeding, as well as the arrangements for the removal of the ash, are very suitable for large establishments; but for small works, where there are only one or two boilers, it would not pay for the cost of construction.

The step grate may, however, be used in a simpler form of furnace, the fuel hopper being replaced by a feed plate,

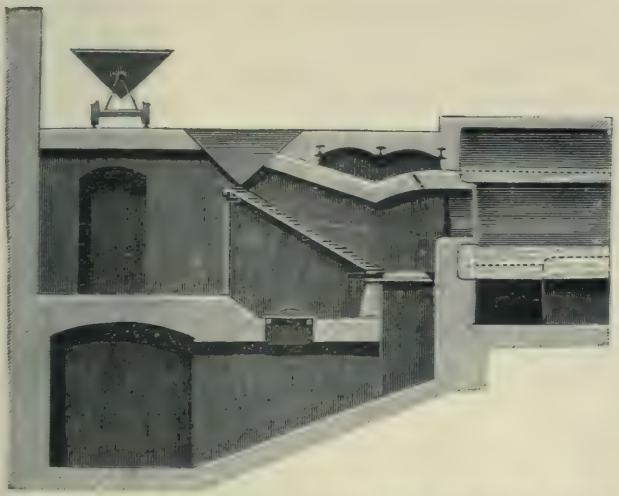

FIG. 8.—Sawdust and Tan Furnace, with Step Grate and Truck for Conveyance of Fuel.

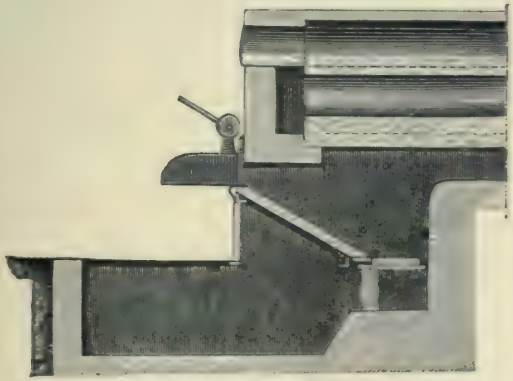

FIG. 9.—Sawdust and Tan Furnace with Step Grate and Feed Plate.

from which the fuel is thrust from time to time towards the grate with a hoe.

In Fig. 11 a construction is shown in which the fuel is thrown into a shaft, at the bottom of which it is carried forward by an endless screw to the fire-grate. This is a very costly construction, on account of the mechanical complication and consumption of power, and will not, as a rule, prove remunerative.

Respecting the above forms of furnace, the following remarks may be made: In most furnaces it is an essen-

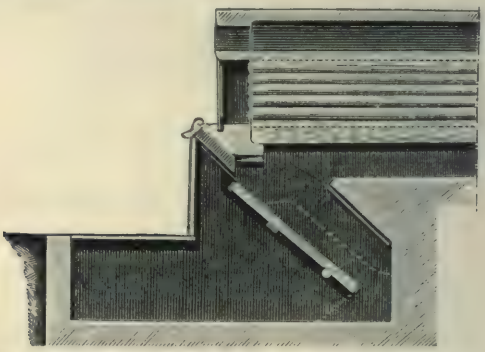

FIG. 10.—Sawdust and Tan Furnace with Step Grate and Fuel Hopper.

tial condition that fresh fuel should be placed on the grate only at such a rate as suffices to replace that which burns away. When the fuel is fed to the grate by hoppers or shafts this condition is not fulfilled, for in the narrow parts of these hoppers or shafts the material is found to become tightly packed, in the parts indicated by the dotted lines *a* in Figs. 6 and 7.

Unless the stoker is constantly stirring the fuel, it burns down on the bars, leaving free spaces through which an excess of air enters and cools the gases. The steam pressure falls; the stoker is obliged to urge the fire, and usually in

doing so throws a large quantity of fuel on the grate. Then, in consequence of the layer of fuel on the bars being too thick, the air supply becomes deficient, combustion is then imperfect and smoke is produced. These disadvantageous conditions are repeated at longer or shorter intervals, according to the care bestowed on the stoking : in addition, cold air obtains entrance to the fireplace whenever the fire-doors are opened for the purpose of poking the fuel

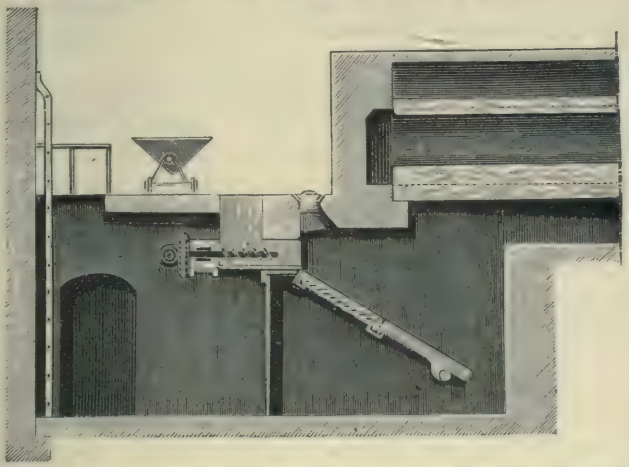

Fig. 11.—Sawdust and Tan Furnace with Step Grate and Charging Slot.

In the earlier forms of furnace mentioned above, the rate of addition of fresh fuel is entirely dependent on the care or attention which the stoker gives to the work. Every time fresh fuel is thrown on, it lowers the temperature ; in addition, the admission of cold air when the fire-door is opened has the same effect. However careful the stoker may be it is impossible for him to keep the fire-grate covered with an equally thick layer of burning fuel throughout, to avoid smothering the burning material by the addition of the fresh fuel, or to regulate the air supply properly.

The arrangement in Fig. 11 is designed to provide for an automatic supply of fresh fuel, independently of the stoker, but it does not altogether avoid the above defects. The supply of fuel by the action of the screws is only regular if the material itself is perfectly uniform. With a material of uneven size there is a tendency for open spaces to form on the fire-grate, and the consumption of steam is never so regular that the supply of fuel to the grate will exactly keep pace with it; hence there are times when the air supply is either in excess or deficiency. The arrangement is likewise costly and complicated.

None of these arrangements therefore supplies the combustible material exactly at the rate at which it burns away, and this leads to a waste of fuel; the escape of the invisible gas, carbon monoxide, by the chimney being almost as much a loss of combustible matter as the production of smoke and soot. On the other hand, when the air supply is in excess, the draught takes place principally through the uncovered places on the fire-grate, whilst the thicker layer of fuel at other spots will be in a comparatively sluggish state of combustion.

Furnace of Herm, Böttger & Co. of Dresden, for Sawdust, Dyewood, Tan, etc.—The principle of this furnace is the establishment of the correct proportion between fuel and air supply, and the intimate admixture of the fire-gases in the combustion chamber. The former object is attained by an automatic conveyance of the fuel to the grate, the latter by appropriate subdivision of the gas currents in the combustion chamber. By this means a more complete utilisation of the combustible material is attained, the formation of smoke and carbon monoxide, if not altogether prevented, being reduced to a minimum.

The arrangement of the individual portions of the furnace aims at fulfilling this fundamental condition. The grate, which consists of several portions, is laid with a certain slope, receives the fuel from a hopper, and so distributes

the layer of burning material that the air obtains proper access to it. The fuel hopper, which is placed at the upper part of the fire-grate, is so constructed that neither in the hopper nor at its junction with the fire-grate can the fuel become compacted. On the contrary, it allows the fuel to fall gradually on to the grate by its own weight as fast as it burns away.

The fireplace is surrounded on four sides by brick walls at definite distances apart, with openings so arranged that the gas currents are subdivided and intimately mixed, thus ensuring the complete combustion of the hydrocarbons and carbon monoxide evolved from the layer of fuel.

The fuel hopper is replenished from time to time to prevent the amount of burning material on the grate from undergoing diminution; the layer of fuel on the sloping face of the grate is in a full state of combustion over the lower two-thirds of the grate area, whilst at the upper part water-vapour and combustible gases are escaping. The combustion is a gradual one; the drying of the material taking place in the hopper, and at the junction of same with the grate; the most intense combustion goes on in the middle, and the complete combustion at the lower part of the grate.

The principal advantages of Böttger's furnace are as follow:—

1. The proportion between combustible matter and air supply is the most favourable one, at the same time the gases are thoroughly mixed.

2. The evolution of smoke and carbon monoxide, if not completely avoided, is reduced to a minimum, consequently the utilisation of the combustible matter is on the average 30 to 45 per cent. higher than in other cases.

3. The feed, however large the amount required of fuel, is simple and appropriate, and the labour small.

4. The stoker has a complete view of the fireplace, while in most cases the fire maintains itself, even if unattended

for more than 24 hours, so that there is no need to relight it every morning.

5. The fire requires less frequent stirring, and less chimney draught as a rule than in other furnaces.

6. The parts exposed to the action of the fire suffer less injury, and the fire-brick lining is of a simple character, consisting of smooth walls and arches which are easily constructed.

Sawdust Furnace for Production of Gas.—An improvement in the utilisation of sawdust may be effected by heating it in an atmosphere of certain gases; the experiments which have been made in this direction having yielded good results as regards both the products of distillation and their yield, and the quality of the charcoal obtained. The gas employed may be either that derived from the sawdust itself or ordinary coal gas introduced into the retort from outside.

In experiments made with coal gas, the gas was passed into the retort at a certain pressure, which had the effect of removing the products of distillation more rapidly from the region of high temperature. The results obtained were favourable, but the decomposition of the products of distillation could only be partially prevented. In consequence of this, the method was altered so that the heat, instead of being applied to the material after issuing from the containing retort, was generated inside in direct contact with the substance to be distilled. All the gases employed in this manner must be completely free from oxygen, in order that no loss of the valuable products of distillation may take place.

One of the older arrangements is shown in Figs. 12 and 13. The furnace is constructed of slag-bricks with an inner fire-brick lining, and the heat obtained from it is employed in roasting the ore in a copper refinery. The first gas producers constructed were furnished with charging cylinders 3 feet in diameter, since the consolida-

tion of the fuel by the formation of tar was feared; but with these a loss of gas was found to be unavoidable. At first the cylinders were closed by cast-iron covers, but it was found that small explosions were liable to occur in the gas tubes, especially with an excess of air in the ore furnace. To ensure equable distribution of the fuel in the producer a sheet-iron tube, *a*, is fixed to the cover with screws. A layer of the combustible material 5 to 6 feet thick must

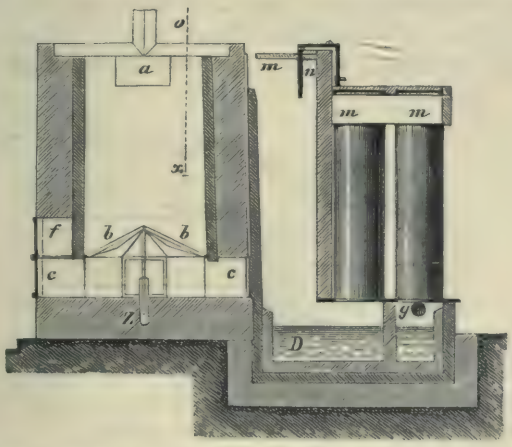

FIG. 12.—Sawdust Furnace for Gas Producers (Section through the Furnace and Condensers).

be kept on the grate; and the height of the layer can be regulated by means of the rod, *o x*. The air-blast enters the furnace through a cast-iron pipe, *z*, which is covered with a cap to prevent the ash from falling into the air tube, and to subdivide the blast; above this is a pyramidal grate built up of eight segments, on which the fuel rests. For cleaning the grate there are four openings *c*, *c*, at opposite points. The air pressure employed is generally $\frac{3}{4}$ inch; for sawdust it should not exceed $\frac{1}{2}$ inch. The older patterns, which had no grate, and

in which the air-blast was introduced through three tuyères, did not prove satisfactory. The grate is now made of cast-iron; when sawdust is used alone the space between the upper edges of the fire-bars should be about $\frac{5}{8}$ inch wide; for a mixture of sawdust and peat $1\frac{1}{4}$ inch and for peat alone $1\frac{1}{2}$ inch. Above one of the openings, *c*, *c* there is another opening, *f*, which serves for withdrawing the fuel when the work is discontinued.

The openings are so constructed that the fire-bars can be inserted or removed through them. It sometimes happens especially when small peat is being used that

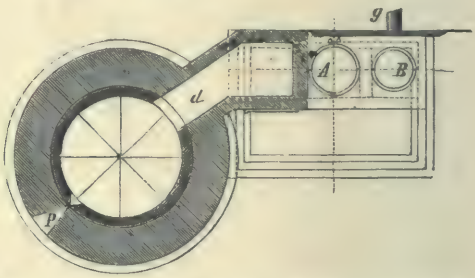

FIG. 13.—Sawdust Furnace for Gas Producers (Ground Plan of the Furnace and Condensers).

soot collects in the channel, *d*, which connects the producer with the condenser. For removing this soot an opening in the wall of the gas generator is provided. This opening is closed by a plate built into the brickwork, and pierced by a hole through which passes the shaft of a steel scraper, which fits the hole. The scraper, when not in use, is drawn back into a recess in the wall. Through *d* the gases pass to the condenser, A, B. This consists of two cylindrical vessels, closed at both ends, and containing tubes through which the gases are conducted, whilst cold water, introduced at the bottom and allowed to flow out at the top, circulates round them. The cylinders are constructed of sheet-iron

$\frac{1}{8}$ inch thick, the brass tubes are 9 feet 9 inches long and $1\frac{7}{8}$ inches in diameter. The water-supply pipe is $2\frac{3}{4}$ inches in diameter. Usually only one condenser is used for each producer. When the gases have passed through the condensers they are conducted by pipes to the furnace. The water and tar condensed from the gas collect in the tank, D, which is constructed of two thicknesses of slag-bricks and one of fire-bricks, with intermediate layers of a mixture of tar and cement. The tar flows over into storage vessels through the pipe *g*, whilst the water runs away by a gutter after it has been completely freed from tar by passing through a straw filter.

A producer consuming 620 bushels of sawdust daily yields about 440 gallons of gas-liquor. When the blast is on, the temperature of the gas increases considerably; and to protect the brass tubes a jet of water is introduced through the roof of the vertical channel which conveys the gas from the producer to the condensers. The water pipe is inserted through a hole in the valve, into which an iron plug is fitted. For distributing the water a baffle plate is fixed opposite the jet. The tubes in the condenser very rarely become choked; but if this should occur, the supply of cold water is diminished so that the gases may pass through the pipes warm, the stoppage being then soon cleared away. The apparatus is liable to the occurrence of small explosions, but these are generally occasioned by defective working of the producer. If the sawdust is too damp it often causes explosions; cavities are formed during the sinking of the charge, and in these air and gas become mixed. To provide against damage from these explosions, valves are placed in the roof opposite to the gas passage. These valves open when an explosion occurs and immediately close again. They are constructed of cast-iron, and being so arranged that they cannot be lifted beyond a right angle, they therefore close again by their own weight. The air-supply pipe is fitted with a safety-valve, as close to the

gas producer as possible, which, in the event of a stoppage of the blowing apparatus, closes the air pipe and prevents it from getting filled with the combustible gas. Such stoppages are very liable to occur from the driving-belt slipping off the pulley of the blowing apparatus. This valve consists of a wooden frame on which leather is stretched; it is hung by a leather strap in a wooden valve-box, and the frame is so light that it is lifted by the air pressure: whereas, on the other hand, if a back pressure occurs, the frame falls and closes the air pipe. The top of the valve-box is formed of a stout sheet of paper glued down, and above this a wooden cover. These form a safety-valve in the event of gas obtaining admission to the tube between the producer and the valve. The combustible material employed in the producer may be sawdust, mixed with small coal, peat, etc. If it is desired to use a different material, it is only necessary to introduce suitable fire-bars, and to increase the strength of the blast when the spaces between the bars are smaller. Each gas producer using sawdust yields 36¼ gallons of tar daily. A special arrangement is employed for collecting the gases from several producers in a single main. It consists, for each of the four producers, of rectangular cast-iron chests of different sizes. The medium-sized one receives the gases from the smaller ones and delivers them to the hydraulic main: all the small chests are fitted with conical valves.

The Lundin Furnace.—In this furnace an air-blast is used both to supply the air required for the combustion and to generate gas, also a condenser is introduced to cool the gases and the water-vapour which they contain. The combustible gases generated in a gas producer fed with sawdust, and provided with an air-blast below the fire-grate, are conveyed by a siphon tube into a box-shaped condenser through the cover of which several fine jets of water are introduced. The jets of water impinge upon pointed pieces of metal placed opposite to the openings, and the water

being thus scattered in all directions cools and condenses the vapours. In order that the condensation may be as perfect as possible, the gases, after leaving the condenser, pass upwards through a channel filled with iron lattice-work over which water is flowing, and thence into a valve-box from which they are distributed, through Siemens' regenerators, to the furnaces where they are to be used. When employed to heat puddling furnaces each hundred-weight of bar iron consumes a quantity of sawdust equivalent to $\frac{3}{4}$ ton of wood-charcoal (2 tons of sawdust are equal to $\frac{1}{5}$ of a ton of wood-charcoal).

As the result of various trials the Lundin gas producer does not seem to be particularly advantageous to the iron manufacturer. This is due to the fact that a producer worked with a blast generates more carbon dioxide and less monoxide than one worked with a chimney draught, and that in the condenser, not merely water, but also tar is condensed, which otherwise would have added to the heat effect. For the complete condensation of the tar very large quantities of water are required (8640 cubic feet in 24 hours).

It is only as a sawdust furnace that the Lundin apparatus has any value, this material being obtained in enormous quantities in Sweden.

The assertion that the system of condensing the tar (which would else have interfered with the working of the valves) has alone rendered the regenerative system possible in Sweden, is not correct, since regenerative furnaces constructed on other patterns are in full and uninterrupted work.

The introduction of water jets is a new and peculiar feature of the Lundin condenser. With the exception of the suitability of Lundin's apparatus for the combustion of sawdust, a very restricted use of that system is to be expected in countries where the same conditions do not obtain as in Sweden, since it would be only an expensive way of wasting any fuel of greater value.

From another source we have the following report :—

"The use of this furnace deserves to spread rapidly; it permits the direct use of undried, comminuted, and sulphurous fuel; a considerable economy of combustible matter, diminished production of scoria, a good quality of iron, and great durability.

"At Munksors in Warmland, a furnace worked with sawdust turns out 50 tons of iron in 6 days, with a consumption of 11 to 14 cubic feet of sawdust per cwt. of finished iron, and a loss of 11 to 12 per cent. : compared with former times, the output has doubled, the expenditure of fuel diminished by $\frac{1}{3}$, and the loss of iron by 1 per cent."

GODILLOT'S FURNACE WITH PYRAMIDAL GRATE FOR PULVERULENT FUEL.—This furnace avoids the usual inconveniences of those which are fed with fuel, especially tan, sawdust, etc., through hoppers in the crown of the arch. In the latter case the pulverulent material, falling on a horizontal grate, forms a heap which becomes consolidated by its own weight. Under these circumstances the air penetrates with difficulty into the interior of the heap and the combustion is incomplete.

The system of pyramidal grates is applicable to all furnaces in which the fuel is introduced through hoppers.

The grate, which is of pyramidal form, is placed above the ordinary fire-bars, serving to support the pulverulent fuel which falls on the inclined faces from the charging hopper above. By this means a more uniform layer of fuel is formed, the air penetrates the whole mass more readily, and the combustion is greatly improved. Each of the charging orifices in the crown of the furnace is fitted with a pipe, which is somewhat contracted towards the upper part. This pipe forms a sort of hopper, which gives a continuous, automatic feed to the fire-grate.

The arrangement and mode of working the pyramidal grate are such that the stoker, without admitting cold air into the body of the furnace, is able to ascertain the state

of the fire, and to remove ash and clinker from the horizontal grate by means of a poker.

Fig. 14 shows a longitudinal section, Fig. 15 a horizontal section, and Fig. 16 a transverse section of the furnace

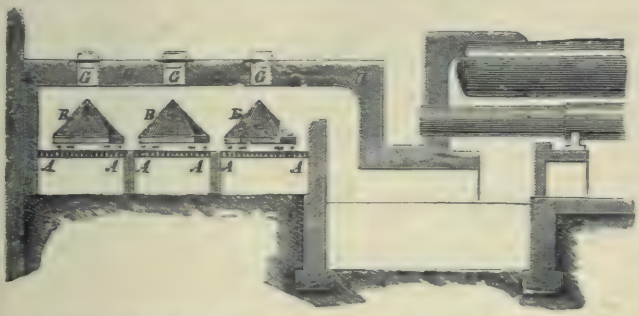

Fig. 14.—Godillot's Pyramidal Fire-grate (Longitudinal Section).

with the pyramidal grate; Fig. 17 the ground plan of one of the pyramids, and Fig. 18 a section of the same, as adapted to a furnace for burning tan, sawdust, etc. The horizontal grate is partly covered by the pyramid. This

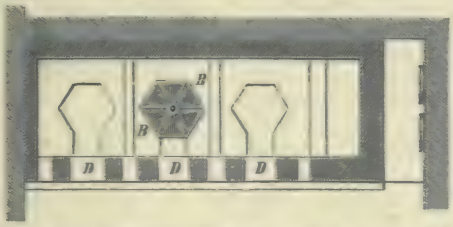

Fig. 15.—Godillot's Pyramidal Fire-grate (Horizontal Section).

pyramid has a number of faces, B, B, B, each of which constitutes an inclined grate. It is slightly elevated above the horizontal grate, A, so that a poker can be inserted between the two for cleaning the fire-bars.

For this purpose a cast-iron trunk, C (Fig. 16), runs from

the door, D, of the fireplace to the horizontal grate in the form of a gutter.

The horizontal grate of the furnace is interrupted below the pyramidal grate, B, and the gutter, C, the inner edge of which rests on it, and allows the ash to collect below the grate, in the form of heaps. By this arrangement the fuel slides down the inclined faces B, since these slope at a

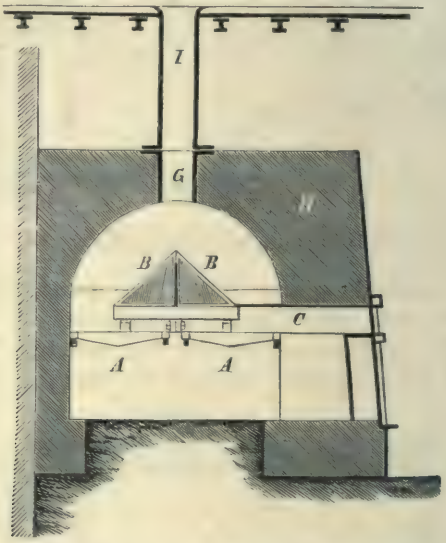

FIG. 16.—Godillot's Pyramidal Fire-grate (Transverse Section).

greater angle than the angle of repose of the material, that is to say, the inclination which the sides of a heap of the substance would naturally assume. It is therefore never necessary to clean the bars of the pyramidal grate, B, for the ash and clinker collect on the horizontal grate, A. The pyramids may be constructed with a greater or smaller number of faces than are shown in Figs. 17 and 18. In these figures six faces are shown, each having the form of a

triangle. The triangles are held together at their bases by screw bolts, but are loose at their apices, so that they may be able to expand. The faces may also be of trapezoid

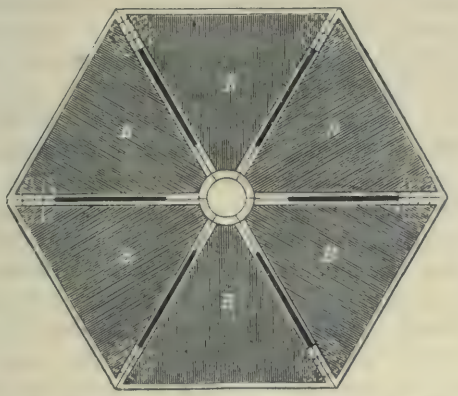

Fig. 17.—Plan of one of Godillot's Pyramidal Fire-grates.

shape, and then form a truncated pyramid, or the grate may be conical and made in one piece. The form of the grate is to some extent dependent on the form and situa-

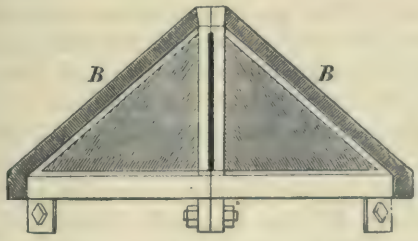

Fig. 18.—Section of one of Godillot's Fire-grates.

tion of the hoppers, which may be cylindrical, square, etc.

The dry or damp fuel is charged in through the openings, G, G, in the crown, H, of the furnace (Fig. 14), but to produce an automatic and uninterrupted feed, a tube, I, may

be carried up from each of the openings, contracting somewhat towards the upper part, serving as a reservoir for fuel.

Swedish Wood-Charcoal Furnace with Condenser.—The apparatus employed in Sweden for converting sawdust into wood-charcoal consists of rectangular chambers 10 metres (33 feet) long and 6·5 metres (21 feet 4 inches) wide below, but narrowed to 4 metres in width (13 feet) at the spring of the semicircular roof, and 6 metres (19 feet 8 inches) high. The side walls have a slight slope inwards. The bottom is flat, except close to the side walls, where it slopes down to a cast-iron pipe which serves for carrying off the gases and condensable products. The former escape through a vertical tube of sheet brass, whilst the latter form a tar deposit on the floor. A rectangular hearth, constructed of fire-bricks, covers half the width of the bottom of the chamber; this is in communication with five narrower pipes, which lead to the ends and sides of the chamber, and by which air is introduced. These pipes rest on tapered iron supports about 9 inches high. The crown of the furnace is protected against rain by a light roof.

Sawdust and other waste from the saw-mills are brought by tram lines, and laid out to dry in the air until required for use. The charging takes place through doors, of which there is one at each end of the chamber. One of these doors, which is flush with the bottom of the chamber, measures 5 feet 9 inches by 4 feet 9 inches, the other is at the base of the arc and measures 59 by 39½ inches. The lower layer of the charge is formed of the larger waste pieces of wood for a height of about 1 foot; upon these the other materials are so placed that the length of the pieces runs parallel to the axis of the chamber. An experiment in which some of the layers were built up of pieces laid crosswise did not give a favourable result, but, on the contrary, occasioned a higher cost for labour.

As soon as the whole charge of wood, which amounts to 16,600 cubic feet, has been introduced, which can be done in 3 to 4 days by 10 men, the lower doors are closed and secured with bolts, and the fire is lit. The upper doors are left open until the third day, to furnish a free outlet for the water-vapour given off from the damp wood. A dark-coloured vapour is evolved up to the middle of the sixth day, after which it generally becomes bluish. The combustion is regulated according to the appearance of the vapour: should the combustion become too vigorous the pipes are partially closed, or the fire is damped in any convenient manner. In order to avoid exposing the structure to internal pressure by thus closing the outlets, the side walls are traversed near the upper part by narrow tubes which are left permanently open. According to the dryness of the wood, the carbonisation may take from 10 to 18 days; 16 days are required for cooling down, and the chamber can be emptied by two men in a day and a half. After any repairs required have been executed a new charge is immediately introduced.

The annual output of one of these carbonisers amounts to 800 lasts (60,800 cubic feet) of charcoal and 160 gallons of tar. The loss due to carbonisation varies according to the dryness of the wood, and may on the average be put at 100 cubic feet, so that the quantity of the charcoal amounts to 85 to 90 lasts, or 6460 to 6840 cubic feet, from which it appears that the yield is 39 to 41 per cent. of the wood employed.[1]

The charcoal obtained from sawdust is less suitable for the blast furnace (Hochofen) than for the refinery (Frischfeuer), especially when it is mixed with ordinary wood-charcoal. The carbonising chambers described above have the advantage over the Meiler (mounds or heaps covered

[1] The statement of yield must relate to bulk, not to weight, the usual yield of charcoal from wood being about 25 per cent. by weight.—(Trans.)

with turf, extensively used in the German charcoal-producing districts) of a smaller cost for labour, and a cleaner charcoal; besides which the work is independent of the weather and requires less skill on the part of the workmen.

Sawdust Furnace of C. Walter for the Manufacture of Wood-Tar.—One of the principal advantages of this furnace is that the grate can never become choked so as to cause irregularity in the combustion; moreover, very fine sawdust can easily be burnt in this furnace without addition of any coarser material. It is used as a source of heat for a bench of two retorts. The fire is regulated by sliding dampers, and can at will be wholly shut off from either of the retorts. The products are charcoal, tar, crude tar-oils, and calcium acetate.

The retorts are set in pairs, and with a slight fall towards the rear. They have at the back two diametrically opposite holes. The lower hole is used both for rotating the (cylindrical) retort when its lower side is burnt out, also for drawing ing off water in the early stages of the distillation, and pitch in the later stages; the upper hole serves for the escape of gases and vapours. Very wide tubes are employed for carrying off the products of distillation. They rise perpendicularly to a height of about 10 feet, and are then carried with a slope of about 10° to the condensing apparatus, which is placed at a distance of about 16 to 19 feet. The vapours have so long a course through these pipes that the more readily condensable vapours liquefy in them and flow back towards the retorts, whilst only the acetic acid vapours, and the more volatile empyreumatic oils, pass on to the condensers and are collected as pyroligneous acid and crude tar-oil. In this way two tarry products are obtained, a thick black tar, and a dark-coloured but fluid tar-oil resembling Finland tar in appearance, which is very much in demand for tarring ships, since it readily soaks into the wood, and acts as a powerful preservative.

Fig. 19 shows a vertical section of the furnace through

the line E, F, of Fig. 20; Fig. 20 a transverse section through C, D, of Fig. 19, and Fig. 21 a section along the line A, B, of Fig. 19.

Through the charging hopper, *a*, which opens above in the floor of the factory, so that the material can readily

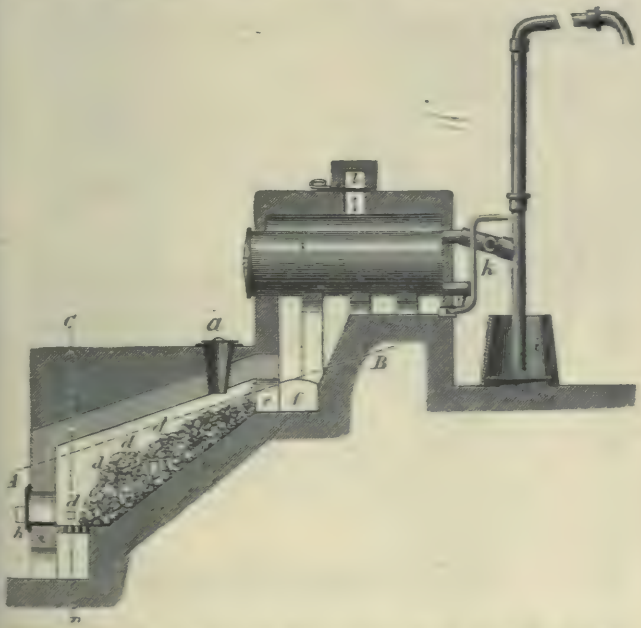

FIG. 19.—Walter's Sawdust Furnace and Stills (Vertical Section).

be brought to it, the sawdust is charged from time to time into the furnace, a fire having first been lighted with some other material. The sawdust slides gradually down the sloping floor of the fire chamber towards the grate *c* in sufficient quantity to supply the place of that which burns away: the amount thrown into the chamber should never be so large that the grate becomes completely covered.

The heap of sawdust burns at the surface, and all that is necessary is that from time to time a poker should be inserted through the door, *h*, to spread it about. If the grate should momentarily get choked (which, however, can only happen if too much sawdust has been thrown in) or if

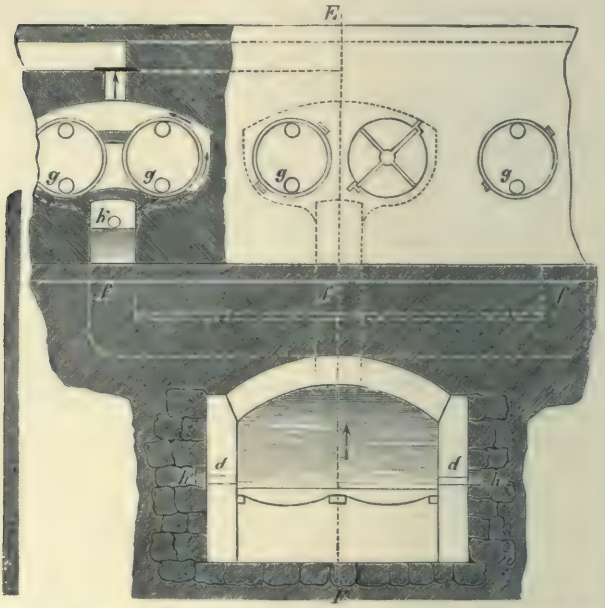

Fig. 20.—Walter's Sawdust Furnace (Vertical Section through the line C, D).

it is desired to admit more air, the air channels, *d*, *d*, *d*, *d*, at both sides of the furnace, may be opened. The ash falls partly through the grate, partly also into the channels, *d*, *d*, which therefore must be so arranged as to be easily cleared. Through the neck, *e*, of the combustion chamber the flame passes into the flues, *f*, *f*, *f*, and is then distributed to the retorts. By means of the dampers, 1, 1, 1 (Fig. 19),

in the flues behind the retorts, the flame can be regulated or shut off from any of the pairs of retorts as required.

A chimney-stack with a good draught is essential. The uncondensable gas which is evolved from the retorts, together with the vapours of acetic acid and tar, is returned from the condenser to the fire by the pipe *k* contributing materially to the heating effect.

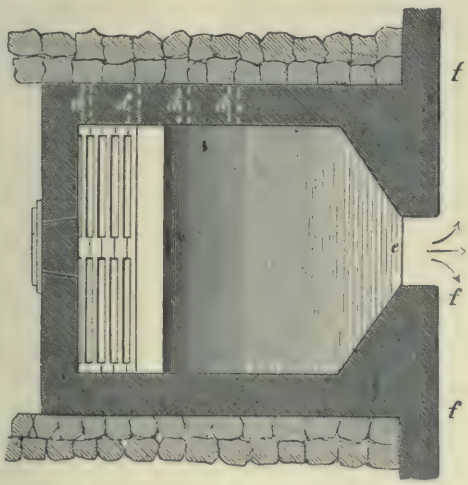

FIG. 21.—Walter's Sawdust Furnace (Oblique Section through the line A, B).

This sawdust furnace differs from others mainly in the fact that, with the exception of the small quantity lying on the grate, the heap of sawdust burns only at its upper surface, so that the obstructions which in other forms of furnace are caused by the subsidence of the mass of fuel with which the furnace is filled cannot occur here.

FURNACE OF NIEDERBERGER & CO. FOR DAMP WASTE-WOOD AND SAWDUST.—This furnace is designed for burning, without previous drying, the wet and finely subdivided

wood-fibre which remains after the extraction of the dye from dye-woods; it is also well adapted for the utilisation of damp sawdust.

Fig. 22 shows the fireplace as arranged for heating a

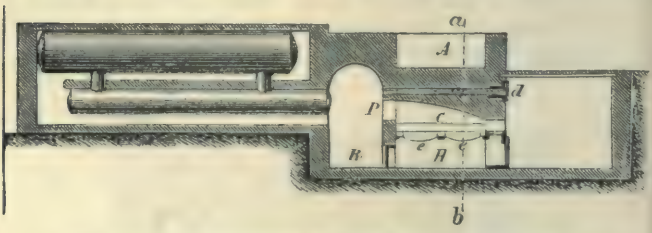

Fig. 22.—Niederberger's Furnace (Transverse Section).

boiler. Fig. 23 is a transverse section through the line *a*, *b*.

The upper space, A, open at the top and enclosed by a wall, serves for the reception of the combustible material

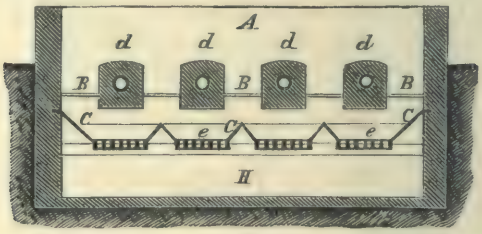

Fig. 23.—Niederberger's Furnace (Longitudinal Section).

which is constantly being thrown into it and piled up in a heap. In the floor of the enclosure, A, there is a row of vertical apertures, B, B, B, under each of which an angle-iron girder, C, with a right-angled, or obtuse-angled edge placed upwards, is situated. The spaces between the lower edges of the girders are filled with fire-bars, *e*, *e*, of the usual construction. The space, H, below C and *e* is the ash-

pit. In front, before the ends of the fire-bars, there are doors or valves, through which the lower layer of the refuse wood resting on C and *e* can be set on fire, the doors being tightly closed after this has been done. In the space above the grates an energetic evolution of gas and smoke is produced from the combustible matter, which, as the lower layers burn away, sinks down on the sloping faces of the girders. The gases pass through the aperture, P, into the chamber, R, into which a separate supply of atmospheric air is admitted through tubes, *d*, which pass through the brickwork of which the bottom of the enclosure, A, is constructed, and which can be closed by either slides or valves, so as to regulate the supply of air to the chamber, R. In this chamber the combustion of the gases takes place, the flame being then conducted into the flues where its heating effect is to be expended. The wood as it descends from the enclosure, A, dries completely before it reaches the grates, *e*, and is regularly delivered to the fire-grates by the sloping surfaces of the girders, C, so that the fire requires no attention as long as a supply of wood is kept up in the enclosure, A.

PETRI'S APPARATUS FOR THE MANUFACTURE OF PREPARED FUEL.—The portable apparatus constructed by Petri was designed with the object of burning a pulverulent or granular fuel by submitting part of it, which was used for kindling the fire, to a preliminary preparation. This treatment is of such a character that the combustible substance can be instantaneously brought, by means of a small flame, into a condition of vigorous combustion, which is then transmitted to the whole mass.

The composition of the powder is such that it absorbs the condensable and combustible vapours given off by heating the fuel. When the fuel has been sufficiently heated, and has given up part of its combustible vapour to the powder, becoming at the same time porous, the latter has undergone the necessary "preparation," and can be

removed to the combustion chamber and set on fire. The powder then readily gives up the vapour of all the volatile hydrocarbons which it has absorbed; these take fire, and by this means the whole of the prepared material is gradually brought into a state of combustion, the porous condition of the heated wood assisting the action of the atmospheric oxygen.

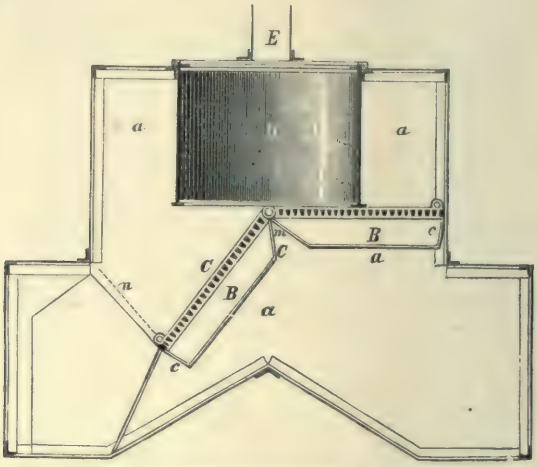

Fig. 24.—Petri's Combustion Apparatus.

The powder consists of dry sawdust, or some other finely subdivided organic substance such as peat dust, with which finely powdered colophony, or some other readily combustible resin, has been mixed. The quantity of colophony added is regulated according to the proportion of volatile constituents already contained in the fuel, resinous fuels such as sawdust requiring a very small amount, coal a larger quantity, and peat and coke the largest of all. The apparatus for heating the kindling material may either be connected directly with the combustion chamber, so that the material which has undergone the necessary prepara-

tion may be directly transferred to the fire-grate, or it may be entirely separate.

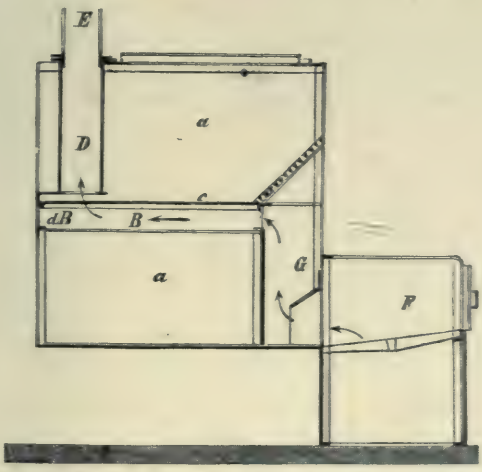

Fig. 25.—Petri's Combustion Apparatus (Transverse Section).

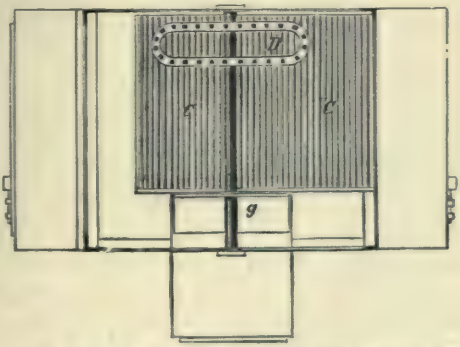

Fig. 26.—Petri's Combustion Apparatus (Ground Plan).

The figures show two forms of the apparatus for the separate preparation of the material (Figs. 24 to 30). Those forms in which the combustion chamber is connected with

the heating apparatus, operate in exactly the same manner as those we are now considering. In the apparatus shown in Figs. 24, 25, 26 (Figs. 27 and 28 show a portable apparatus of the same character for locomotives) the fuel is introduced, in admixture with the powder, into the space, *a*. The bottom of this space is formed of two four-sided

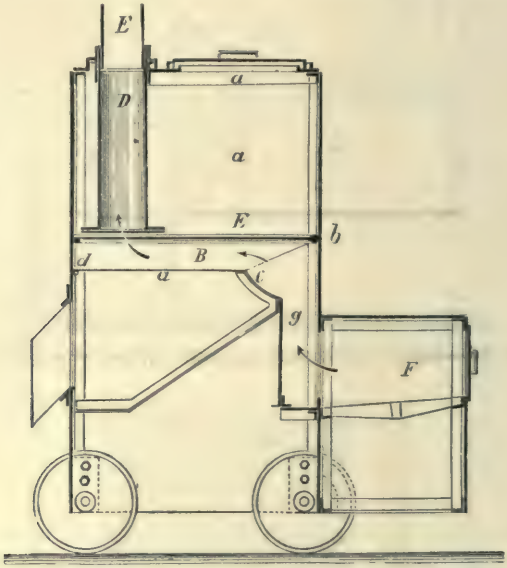

FIG. 27.—Petri's Portable Combustion Apparatus (Transverse Section).

hollow prisms, B, open at one side, the prismatic faces, *b*, *c*, *d*, and the base, *a*, being constructed of sheet-iron, whilst the fourth prismatic face consists of a fire-grate, C.

The prisms, B, can be rotated on a pivot, *m*, and can be kept in a horizontal position by the pulley, *n*. Connected with these two prisms is a vertical chamber, D, the walls of which are constructed of grate-bars, and which opens above into the chimney The fire which heats up the

materials is lit in the chamber, F. The fire gases pass through the chamber, D, parting with their heat on the way. When the material has been suitably prepared, that is to say, heated up, the chains, *n*, are released and the prepared material falls into cases, which are then transferred to the combustion chamber, emptied out upon the fire-grate, and their contents set on fire. The forms shown in Figs. 27 and 28 can also be adapted to locomotives. In this event the material falls directly into the fire-box of the locomotive.

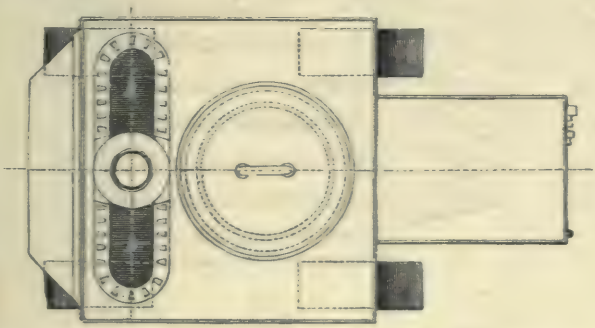

FIG. 28.—Petri's Portable Combustion Apparatus (Ground Plan).

The modified apparatus shown in Figs. 29 and 30 consists of the fuel chamber, *a*, containing a coil filled with calcium chloride solution, and a copper tube, N, heated from the combustion chamber, O. The circulating liquid gives up its heat to the mixture of fuel and powder.

After sufficient warming, the valve, *g*, is opened by the rod, *p*, and the prepared material falls into the cases, P. This apparatus is more expensive to construct than that first described, but affords a more uniform heating of the material and an accurate control of the temperature by means of a thermometer dipping into the calcium chloride solution.

H. Wincklemann [1] is of opinion that wood-waste can be utilised to the best advantage by employing it as a fuel for steam-raising purposes. The calorific value of freshly-cut wood is 3000 to 4000 calories, and that of air-dried wood 4200 to 4500 calories, but wet wood containing 50 per cent

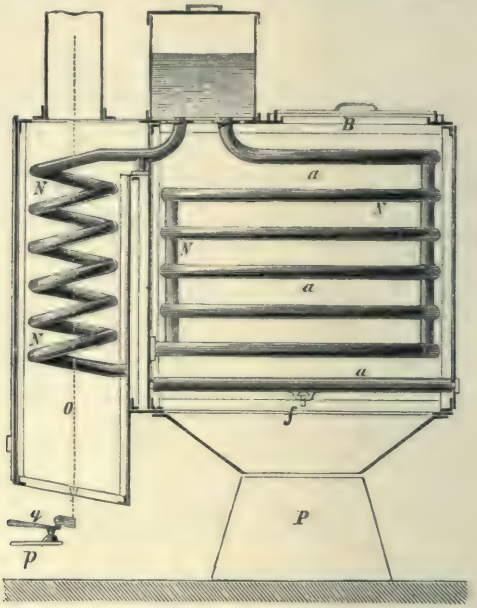

FIG. 29.—Stationary Combustion Apparatus of Petri (Modification).

of water has a calorific value of only 1800 calories, and should on no account be burnt while in this condition. When dealing with sawdust it is best to briquette it. No difficulty will be found in doing this with simple presses and an automatic filling device. A little rosin or pitch can be used as cementing materials, the mixture being heated before pressing. For burning briquettes under the

[1] H. Wincklemann, *Papierfabrikant*, 1912, p. 920.

boilers a long horizontal grate with bars 8 mm. thick and 3 mm. spaces is regarded as most suitable. Waste timber in ½-metre lengths or thereabouts are best burnt on a step grate with an inclination of approximately 30°. Wood requires but little air for its combustion, hence to get the best results the furnace should be kept well charged and the dampers not too full open.

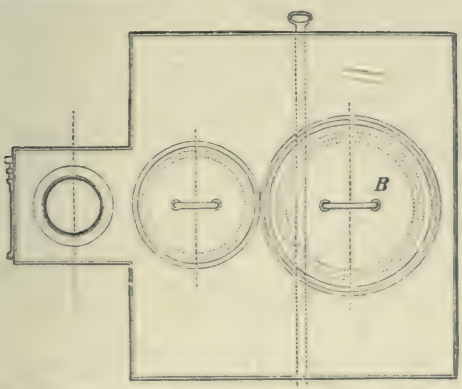

Fig. 30.—Stationary Combustion Apparatus of Petri (Modification).

Use of Wood-waste in Suction Plants.—G. E. Lugo, in a paper read before the Junior Institute of Engineers,[1] refers to the economy which can be effected by those having waste combustible materials at their disposal by employing them in the newer types of suction plants in the place of coal. It is thus possible to utilise all kinds of wood-waste from cuttings of 6 inch diameter to sawdust, also cotton-seed hulls, coconut shells, fibre and dust, spent sugar cane, rice and coffee husks, spent tanning bark, rubber leaf waste, surface peat, etc.

The generator in this case is about 2½ times greater than that used for coal, and it is necessary, in dealing with coarse

[1] *Times Engineering Supplement*, November 12, 1913.

materials like wood, to have a fairly deep bed of fuel, otherwise air passes through and the gas becomes ignited on the surface. With small material, such as sawdust, a shallow layer is essential, otherwise the resistance offered will prevent the formation of gas, and the engine will stop running. The gases leaving the generator are cooled and washed to remove the fine particles of heavy tar and dust, which would otherwise tend to choke the connections. The calorific power of air-dried wood is about 6000 B.Th.U. per lb., and the amount consumed per b.h.p. is entirely dependent upon the percentage of moisture present. In the case of air-dried wood this varied from 10 to 20 per cent., while in fresh-cut timber it ranges from 30 to 50 per cent. When the wood contains 60 per cent. of moisture it must be dried, otherwise it does not carbonise satisfactorily in the generator. When used in a generator wood at 10*s*. per ton is equal to anthracite at 25*s*. per ton, and the gas yielded by it is of higher calorific value, thus wood-gas equals 150 to 170 B.Th.U. per cubic foot, while that from anthracite is 120 to 140 B.Th.U

With regard to the use of wood for steam-raising purposes, the author states that in a steam boiler specially constructed to burn wood refuse, 6 to 10 lb. of the latter was consumed per b.h.p. as compared with 2½ to 3 lb. per b.h.p. for coal. In a test made with a Whitfield producer and an 84 b.h.p. engine running a 105-volt dynamo, 2072 lb. of fuel gave 540 B.O.T. units, which is equal to 3·83 lb. of fuel per kw., the run being of 10 hours' duration and the fuel oak and elm sawdust, and chips from wood-working machinery, which was otherwise valueless. In one factory mentioned, the introduction of a suction plant in which the wood-waste could be utilised led to a very considerable saving, since previously, when using an ordinary steam boiler, it was necessary not only to burn all the waste produced, but also upwards of 500 tons of coal per annum in addition, to obtain the same amount of power.

CHAPTER III

DISTILLATION OF WOOD FOR RECOVERY OF VOLATILE PRODUCTS

Experimental Distillation of Wood-Waste.—J. Lawrence and J. C. Lawrence [1] have made several trials in the distillation of wood on an experimental scale. The plant used by them consisted of a retort or iron cylinder, 5 feet long and 2½ feet diameter, set horizontally on a brickwork base and surrounded by a sheath of asbestos board to equalise the heat, which was applied by gas burners. In one end of the cylinder was an opening, closed during the test by a door which was bolted to a flange, while at the other end a tube was inserted through which pyrometer readings could be taken. The exit tube for the gases was at the top of the end opposite the door, and consisted of a flexible metal tube which communicated with a copper coil condenser placed in a wooden box. The charge consisted of 200 lb. of oak lumber slabs and "off fall" cut into pieces 24 inches × 1 to 2 inches × 2 to 4 inches. The object was to obtain the maximum yield of methyl alcohol and acetic acid, and with this end in view the heat was gradually raised to 100°, and then more quickly to 280°, and, at the point at which heat is developed in the wood itself, (*i. e.* an exothermic reaction took place about 275° C.), the heat was removed and the distillation allowed to proceed unaided. This was found not to be sufficient to remove the whole of the products, so that as soon as the distillation slackened, which was indicated by a fall in temperature,

[1] *Jour. Soc. Chem. Indl.*, 1911, 728.

external heat was again applied until the temperature rose to rather over 400° C.

The following table shows the yields obtained, which are compared with two experiments of Senff, recorded at the foot of the table, which were done with the same kind of wood, *i. e.* red oak.

PARTS PER 100 OF WOOD USED

No.	Condition of wood.	Acid liquor obtained.	Crude alcohol from acid liquor.	Acetate of lime from acid liquor.	Tars.	Charcoal.	Gas.
1	Green bark on	42·50	0·95	4·55	3·10	29·90	24·50
2	Green bark off	44·25	1·00	4·75	3·58	30·20	21·97
3	,,	36·50	0·85	4·05	2·80	29·20	31·50
5	Air dry clean	40·05	1·30	5·15	3·50	35·20	21·25
6	,,	44·50	1·20	5·05	3·70	31·60	20·20
7	,,	40·65	1·20	5·15	5·75	31·25	24·35
8	,,	42·75	1·15	5·00	3·55	30·00	23·70
9	,,	44·25	0·95	4·95	3·63	31·56	20·56
10	,,	43·75	1·15	5·05	3·45	31·12	21·68
	Averages	—	1·08	4·86	3·45	31·11	—
1	Air dry bark on	44·45	—	4·55	3·70	34·68	17·17
2	,,	42·04	—	3·84	3·20	27·73	27·03

Remarks.—No. 1. Heated slowly. 2. Slower than 1. 3. Rapidly. 5. Sawdust heated slowly. 6. Slightly drier than No. 5, heated slowly. 7. Heated a little more rapidly than No. 6. 8. Ditto. 9. Heated slowly. 10. Ditto. 1. Ditto. 2. Heated rapidly in red-hot retort.

The green wood yielded a greater proportion of acid liquor, but the actual amount of acetic acid was less than when air-dried wood was employed.

The above-named authors have calculated the values of the products, taking as an example of a plant which they are personally familiar with over a period of several months' working. The mill cut 125,000 feet of hardwood lumber, the waste from which, in stumps, slabs, limbs, etc., according to Frankforter's figures, would amount to 883,700 lb. or 196·4 cords. Practically the whole of this was suitable for distillation, and if the average figures in the table be taken for purposes of calculation, with the prices as given in the U.S. Census Bureau Statistics for 1909 as a basis, it would have yielded the following :—

				£
Tar	30,488 lb.	@ 8	cents per gall.	250
Charcoal	274,919 ,,	@ 6	,, ,, bushel	825
Alcohol	9,544 ,,	@ 24	,, ,, gall.	1865
Acetate of lime	42,948 ,,	@ 1·5	,, ,, lb.	644
				£3584

The gas from one of the distillations was analysed, and showed a comparatively high calorific value.

	Per cent. by Volume.
Heavy hydrocarbons	8·16
Marsh gas	12·32
Carbon dioxide	31·45
Carbon monoxide	35·08
Hydrogen	10·94
Nitrogen	2·05
	100·00
Calorific value	11,493 B.Th.U. per lb.

The distillation of Western conifer woods has also been studied by H. K. Benson and M. Darrin [1] in a plant erected for the United States Forest Service at the University of Washington, the capacity of the still in this case being about half a cord.

[1] H. K. Benson and M. Darrin, *Jour. Ind. Eng. Chem.*, 1915, 916.

The following are the average results obtained :—

Material.	Weight per cord.	Turpentine and light oil.	Wood alcohol.	Acetate of lime.	Tar.	Charcoal.
	lb.	U.S.A. galls.	U.S.A. galls.	lb.	U.S.A. galls.	lb.
Douglas fir, common mill waste	3330	3·40	3·90	75·0	27·80	977
Douglas fir, selected resinous waste	4250	10·86	3·71	74·3	46·37	900
Douglas fir, stump wood .	3260	5·59	2·60	55·8	19·88	675
Western yellow pine, mill waste	2840	4·91	3·25	73·4	24·80	478
Western yellow pine, stump wood	2620	6·06	1·83	60·8	23·05	520
Western hemlock, mill waste	3270	2·76	5·00	94·0	21·00	938

ZWILLINGER'S APPARATUS FOR CARBONISING SAWDUST, ETC., WITH RECOVERY OF THE VOLATILE PRODUCTS.—The apparatus consists in general of a steam superheater (with the requisite boiler for producing the steam), of a cast-iron cylinder for the carbonisation of the material, of the ammonia apparatus, hydraulic main, cooler, and lead vessels, and the apparatus for the illuminating gas, such as the gas purifier, holder, and tank. The carbonisation cylinder is filled from above from a charging reservoir of the same capacity, and it is emptied below into sheet-iron vessels of similar size. The carbonisation is effected in the cylinder by means of superheated steam at a temperature of 750° to 800° C., whilst at the same time the cylinder is surrounded through its whole length by the waste flue gases from the superheater, before these pass off by the chimney. A furnace with four cylinders will require 16 kilos. (35 lb.) of coal and 50 kilos (110 lb.) of steam per hour.

The superheated steam, which is admitted direct to the

cylinders, passing thence through the hydraulic main and the cooler, raises the pressure in the cylinders, thus sweeping out the gases and vapours through the sulphuric acid absorbers and gas purifiers into the gas holders.

The working of the apparatus is free from danger, pro-

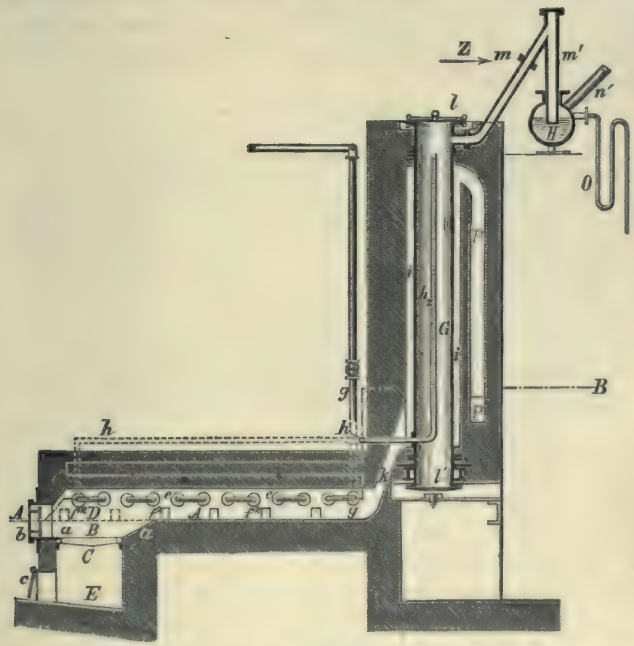

FIG. 31.—Zwillinger's Apparatus for Carbonising Sawdust (Vertical Longitudinal Section).

duces no nuisance, and is in the highest degree simple and convenient.

The wear of the gas and condensing apparatus is so small that its durability for many years without repairs may be counted on with certainty. The carbonising cylinder and the superheater, when worked continuously, will run for

at least three years without requiring any expenditure for repairs.

In order to maintain a uniform heat in the superheater furnace, and to ensure complete combustion of the fuel, the fireplace is so built, by giving a batter to the side walls, *a*, *a*, lowering the fire-bars, and introducing a vertical fire-brick partition wall, C, that two fireplaces, D, D, are formed, each of which is furnished with a fire-door, *b* (Figs. 31, 32 and 33).

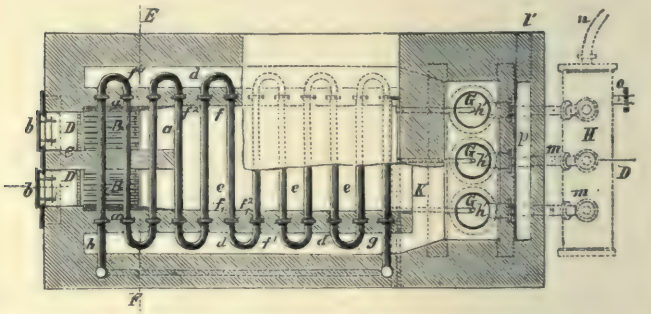

FIG. 32.—Zwillinger's Apparatus for Carbonising Sawdust (Horizontal Section).

For regulating the air supply, each ash-pit, E, is fitted with an adjustable door, *c*.

In the superheating chamber, A, straight tubes, *e*, *e*, are supported on dwarf walls, *f*, *f*, and are connected by elbows *d*, *d*, which project beyond the dwarf walls on both sides into narrow channels, *f'*, *g*, which communicate with the fireplace by pigeon-holes. The superheating chamber is not arched over, but covered with flat plates, which are supported by the walls, *f*, *f*. The steam enters at *g*, traverses the pipes, *e*, *e*, which are kept at a dark-red heat, and is then carried by the pipe, *h*, in a highly superheated condition, to the carbonisers, G, G, G. The cylinder, G, which holds about 150 to 200 kilos (233 to 440 lb.) of the

material to be carbonised, is constructed of cast-iron, and is furnished with covers, 1 and 1′, at the top and bottom respectively, for filling and emptying it. Each cylinder contains a pipe (branching from the steam-pipe, *h*) which is pierced with small holes throughout its entire length, through which the superheated steam is passed into the substance to be carbonised. The carbonisation cylinders, which are most advantageously 12 inches in diameter,

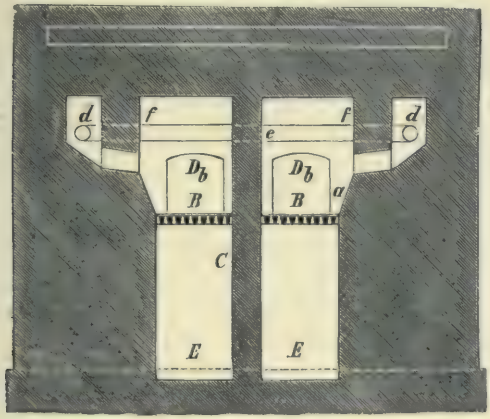

FIG. 33.—Zwillinger's Apparatus for Carbonising Sawdust (Transverse Section through the Superheater Furnace).

may either be placed vertically or horizontally, and are so set in the brickwork that a flue is left all round them, which communicates by pigeon-holes with the superheating furnace, A.

The heated gases issuing from the fireplace, D, are caused to pass through the superheating chamber, A, and through the channel, *k*, into the flue, *i*, which surrounds the cylinder, C, by which means the steam-pipes, cylinder, and surrounding brickwork are all raised to a high temperature; the products of combustion then pass to the chimney

by the flue, p, p'. The containing walls must be thick enough to prevent any material loss of heat by radiation and the heat of the gases is so far absorbed that they escape into the chimney at a temperature of about 160° C. The gases and vapours evolved during the carbonisation are carried by the pipe, m, m', into a hydraulic main, H, from which they pass by the pipe, n, to the cooler. A syphon tube, O, branching off from the hydraulic main, keeps the acid liquor in the main always at a constant level. To prevent the iron pipes of the superheating apparatus, and the cast-iron carbonisation cylinder, from being burnt out by the oxygen in the hot gases, these are covered with a refractory lagging, which not only resists high temperatures, but adheres firmly to the iron, and does not crack, melt, or peel off. This is composed of 100 parts of fire-clay, 20 parts of common clay, 40 parts of powdered bone-ash, and 2 parts of cow-hair or barley chaff. The fire-clay and the bone-ash must be dried and powdered, and then mixed with enough water to form a uniform plastic dough of the consistence of glazier's putty, into which the cow-hair or the barley chaff is then thoroughly kneaded. With this composition the superheater tubes are covered to the thickness of about $\frac{1}{2}$ an inch, and the carbonisation cylinder with $1\frac{7}{8}$ inch. They are allowed to dry for 24 hours, and may then, at once and without risk, be exposed to a red heat of 1000° C. Carbonisation apparatus, similar to the above, may advantageously be used for the production of coal gas with recovery of the by-products.

The carbonisation apparatus serves for the production of charcoal from the waste materials mentioned above, and for the recovery of the products of distillation, such being pyroligneous acid, acetate of lime, acetic acid, illuminating gas, tar, *Oleum cornu cervi*, etc.; it can be employed for the utilisation of exhausted dye-woods, tan, sawdust, fir cones, horse chestnuts, fruit stones, nut and almond shells,

etc., and effects the carbonisation with superheated steam at a temperature of 750° to 800° C.

The yield obtained from 100 parts of sawdust, exhausted dye-wood, or spent tan, is as follows :—

Charcoal	21	to 23	per cent.
Tar	7·9	„ 8·6	„ „
Pyroligneous acid (5 per cent. of wood-spirit and 6 per cent. of acetic acid)	35	„ 45	„ „
Gas	20	„ 23	„ „

The last is equivalent to 1400 cubic feet from each charge of 2 cwt., requiring 60 to 65 minutes to distil.

The tar obtained by distillation with superheated steam is especially distinguished by the fact that the tar oils obtained from it are particularly easy to purify, and yield very pure products. Moreover, this method of carbonisation gives a larger yield than was the case with any carbonisation furnace previously in use.

The gas may either be employed for illumination, or, where there is no demand for such purpose, may be used for raising steam in the boiler.

Fischer's Apparatus for Carbonising Wood with Recovery of the Volatile Products.—This apparatus, shown in Fig. 34, consists of three superposed portions, namely, two vessels set in brickwork, and a removable reservoir, which is omitted in the figure. These three vessels, which can be closed air-tight, are connected with one another by several tubes, provided with stop-cocks. Each vessel is furnished with a stirrer and a thermometer. The upper vessel (" Drier ") is fitted with a supply pipe for the admission of steam superheated by waste heat, or else of dry, warm air; the lower vessel (" The Carboniser ") is in communication with a vacuum pump. The tubes which carry off the gas and volatile products from both vessels are closed at their outer ends by hydraulic seals, and at their inner ends with arrangements for arresting

dust. The " Drier " is kept at as constant a temperature as possible, by the waste heat from the lower vessel, as well

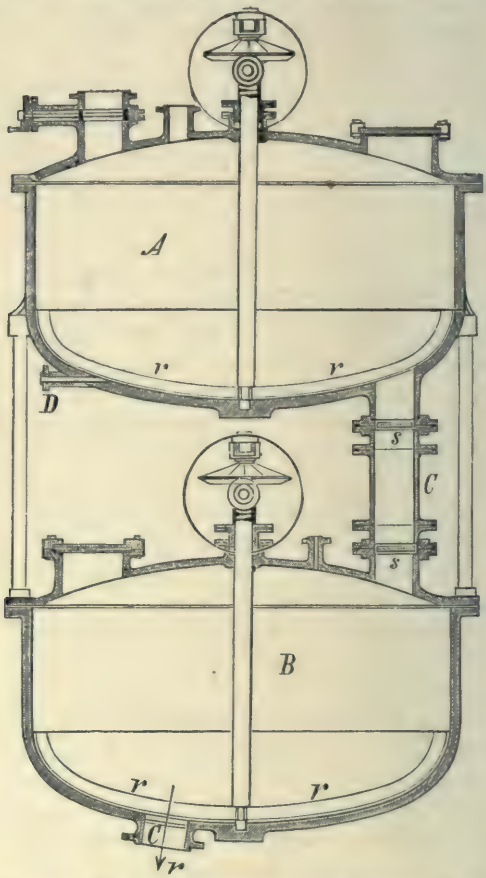

Fig. 34.—Fischer's Apparatus for Carbonising Wood.

as by the combustion of the uncondensable gases obtained during the carbonisation. The " Carboniser " is heated by a direct fire or by producer-gas.

The material to be carbonised is fed into the " Drier," the stirrer of which is kept in motion, and in which a constant temperature of about 130° C. is maintained, whilst dry steam or heated air is blown in. By their direct contact with the wood a rapid drying, and at the same time a disintegration of the wood is effected. When the drying is complete the contents of the vessel are transferred by the stirrer to the " Carboniser," on opening the valve between the two vessels. The stirrer of the lower vessel is kept running while the temperature at the time of filling will be about 150° C. As soon as the upper vessel is empty, the valve communicating with the lower is closed, and the chamber is recharged, whilst the lower vessel is now heated to the carbonisation temperature at such a rate that it gives the largest yield of crude acetic acid and the smallest proportion of uncondensable gases. Whilst the " Carboniser " is being raised from 150° to the carbonising temperature, it is evacuated as completely as possible by the attached air pump, after which dry steam, or an inert gas, is admitted in place of the air until the pressure in the vessel is again equal to that of the external atmosphere. The carbonisation then goes on out of contact with air, so that combustion of the gaseous products of distillation is rendered impossible. The result is a higher yield, especially of wood-spirit (methyl alcohol), than is the case with earlier carbonisers. The volatile products are drawn over into a cooler. When the carbonisation is complete the stirrer is stopped, and the vessel and its contents are allowed to cool down to about 150°, whereupon the granular wood-charcoal is discharged by the stirrer into a receptacle in which it is allowed to become completely cold out of contact with air. The " Carboniser " is then filled afresh.

Halliday's Apparatus for the Production of Pyroligneous Acid.— The apparatus constructed by Halliday is a continuous one, consisting of a cylinder with a feeding screw. According to the speed with which the

screw is driven, the wood can be exposed for a longer or shorter time to the action of the heat, and thus a larger yield of acetic acid is obtained than is possible in the case of charcoal heaps. This fact is, however, not attributable to any especially favourable construction of the apparatus, but exclusively to the form of the raw material. From small fragments of wood the distillate is much more rapidly evolved than from large billets, and the distillate undergoes

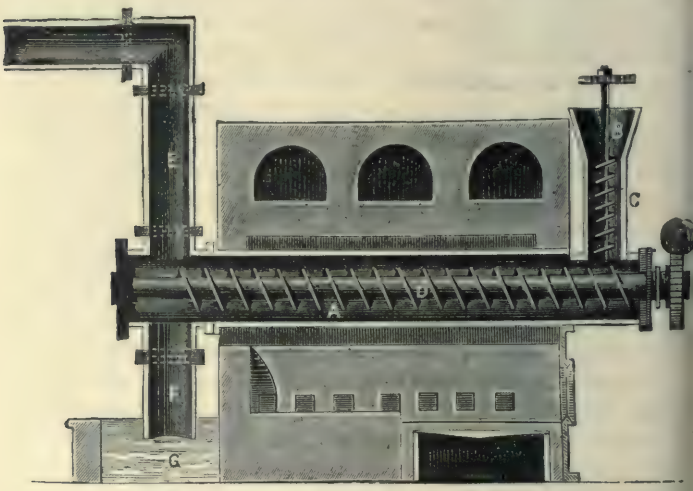

FIG. 35.—Halliday's Carbonisation Apparatus.

less decomposition in the apparatus. Two cwt. of sawdust yields from 10 to 12 gallons of a liquid containing 4 per cent. of acetic acid, besides $1\frac{1}{4}$ to $1\frac{3}{4}$ gallons of tar.

The sawdust is thrown into the hopper, B (Fig. 35). In this hopper a revolving screw, C, delivers the material at an appropriate rate into the horizontal cylinder. The latter is heated by the furnace, A. A second screw, D, keeps the material in the retort in constant motion, and at the same time conveys it gradually to the other end of the

cylinder. The wood becomes carbonised as it traverses the cylinder, so that by the time it reaches the farther end it has been deprived of all its volatile products. Two pipes are connected with this end of the cylinder. One of these, F, descends into an air-tight closed cast-iron receiver, or else into a cistern, G, filled with water; the other, E, carries off the products of distillation to the condenser, which consists of tubes surrounded with cold water. Some dye-wood grinders convert all their waste wood into acetic acid in this manner, with great advantage to themselves. The yield of acid is almost as large as would be obtained from the original wood by the ordinary methods.

Columnar Distillation Apparatus.—This apparatus, which is also especially suited for sawdust, dye-wood, wood-refuse, and tan, consists of a vertical sheet-iron cylinder about 17¼ feet high and 5¼ feet in diameter, containing a number of superposed bell-shaped rings, each about 4 to 9 inches high, thus forming a kind of annulated cylinder, the lower end of which has the form of an inverted cone.

The wood-refuse charged in at the top is heated in the annulated cylinder, and the evolved vapours rise into the inverted bells, whilst the charcoal is removed at intervals from the bottom. As the lower part of the cylinder can be closed by a valve, the distillation can be carried on, without intermission, by continuously charging the wood in at the upper end. The small charcoal obtained from the distillation of wood-refuse may be made use of in various ways; one part is burnt on suitable grates (step grates) to furnish heat in the factory itself; the remainder, especially when sawdust is carbonised, forms, in the finely divided condition in which it is obtained, a very serviceable disinfectant; in Vienna, where charcoal has a high value as a fuel, it is well adapted for the manufacture of briquettes.

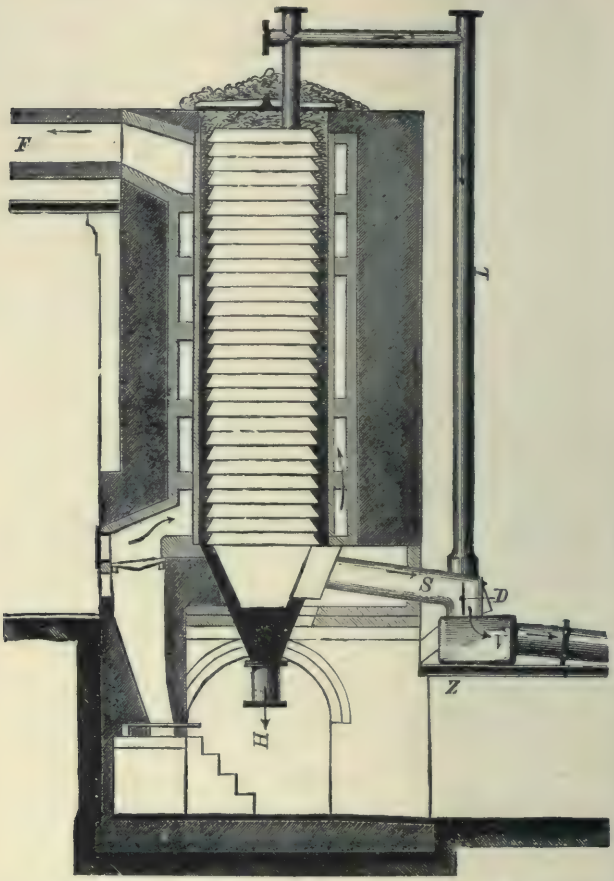

FIG. 36.—Distillation Column for Wood-refuse.

F, Waste Gases; *L*, Light Distillate Gases; *S*, Heavy Distillate Gases; *D*, Throttle Valve; *V*, Receiver; *Z*, To Atmos. Condenser; *H*, Charcoal exit.

WAISBEIN'S DISTILLATION APPARATUS WITH PRODUCER-GAS.—Waisbein made experiments on the application of producer-gas to the dry distillation of wood. The gas was

generated in the furnace, A, by the combustion of wood-charcoal, and was drawn by the ventilating fan, B, which was set in motion by water power, through the retort, C, containing the material to be distilled. The operation was carried on in the following manner: After the retort was charged, the valve, D, and the tap, E (the latter of which supplied water to the fan), were opened as far as was necessary to bring the temperature of the entering gases to 150°, the temperature being observed by the thermometer, *t*. The hot gases traversed the retort, and arrived at the condensing coil, K, loaded with water-vapour. In

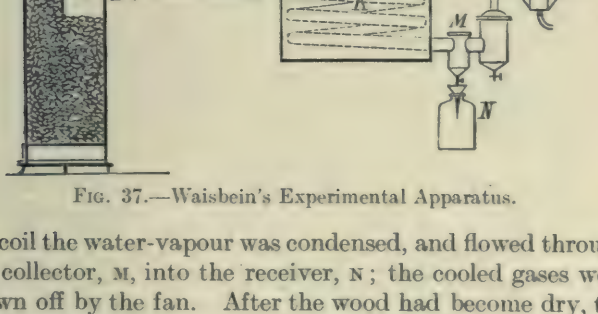

FIG. 37.—Waisbein's Experimental Apparatus.

the coil the water-vapour was condensed, and flowed through the collector, M, into the receiver, N; the cooled gases were drawn off by the fan. After the wood had become dry, the valve, D, and the tap, E, were further opened, so that the gas reached the retort at a temperature of 280°, and the oxygen compounds were collected separately. The valve, D, and the tap, E, were then fully opened; the temperature of the gases rose to 430° C., at which temperature the tar distilled over. The products from birch-wood containing 15 per cent. of hygroscopic moisture were

Water	27	per cent.
Pyroligneous acid, containing 21·8 per cent. of acetic acid	27	,, ,,
Wood-spirit	1·2	,, ,,
Charcoal	31	,, ,,

Pine-wood yielded approximately the same proportions, but the pyroligneous acid contained only 12·9 per cent of acetic acid.

In consequence of the success of these results a larger experimental plant was constructed. In Figs. 38 to 41, A is the gas producer: the fuel is introduced through the doors at the top, through which also enters the air necessary for the combustion. B is the chimney, which, however, is only used when lighting the fire. and is shut off by

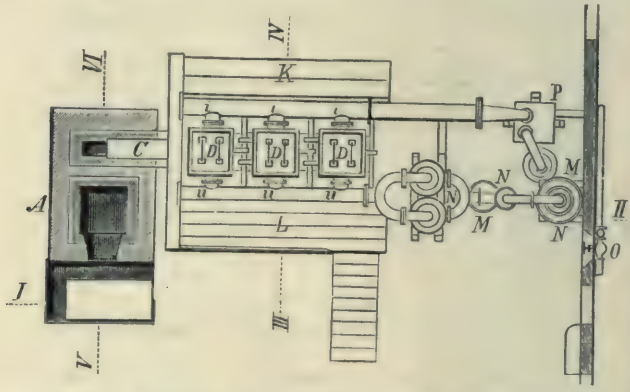

FIG. 38.—Waisbein's Distillation Apparatus (Ground Plan).

the slide valve, *a*, before beginning the distillation. C is the tube which conveys the gas from the producer to the retorts, D, D. The gases and volatile products issue from the retorts by the tube, K or L, according to whether the valves, *i* or *u*, are opened. The hot gases, together with the gaseous products of distillation, carried off by the tube, L, enter the cooler, N. Here the products of distillation condense and flow into the receiver, M, whilst the gases pass into the vessel, P, and from thence are pumped out by a Körting's injector, which is employed to produce the draught through the whole system.

The temperature of the gases entering and leaving the retorts was indicated by the thermometers, t, t'. appeared at the outset that certain errors in the planning of the apparatus had been made. It was discovered (1)

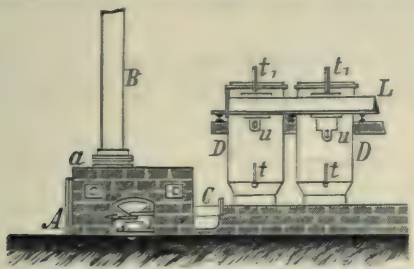

FIG. 39.—Waisbein's Distillation Apparatus (Section through I., II.).

that the temperature of the producer-gas where it entered the retorts was too high; (2) that the cooling surface of the condenser was too small, so that the products of distillation could not be sufficiently cooled. Moreover, the

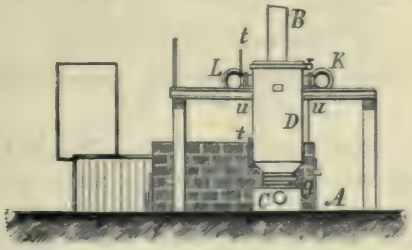

FIG. 40.—Waisbein's Distillation Apparatus (Section through III., IV.).

sectional form of the retorts was not the most suitable. In consequence of the disadvantages thus introduced into the operation, the temperature of the gas which entered the retorts could not be controlled as completely as was desirable. When a temperature of 280° was required the screw

valve, *g*, could only be opened a very little way (5 turns out of 35), and the distillation then occupied an unreasonably long time. If the valve was fully opened the distillation was finished in 45 to 55 minutes, but the temperature rose far above 280°, and the resulting distillate was then contaminated with tar.

The yield of products obtained in the distillation of birch-wood amounted to 95·5 per cent. of the theoretical.

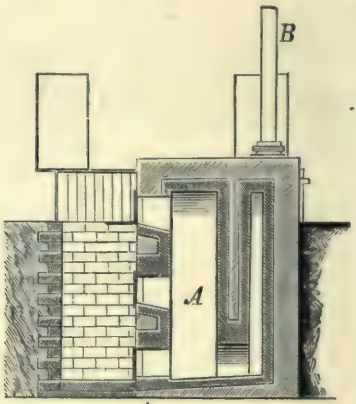

FIG. 41.—Waisbein's Distillation Apparatus (Section through V., VI.).

Hanmer's Distillation Plant (Eng. Pat. 16,543, 1904).—A continuous retort for carbonising peat, turf, wood, and similar materials, also suitable for treating sawdust or wood-waste is shown in Fig. 42. This is the invention of T. R. Hanmer. The retorts consist of two or more cast-iron tubes, A, fixed to and surmounting the brickwork at the base of the kiln over the chambers, B, which connect to the discharging doors, K. The material to be carbonised is raised by an elevator to the platform, L, and is charged through the openings, C, by depressing the cones, *c* which are balanced by the chains and weights W, W. The

gases pass out of the retorts by lateral openings, F, into the down-pipes, G, and then through the liquid in the hydraulic mains, H. The distillation is carried on in the iron tubes, A, the chambers, B, serving for cooling the charcoal. E is the furnace and D, D are chambers through which

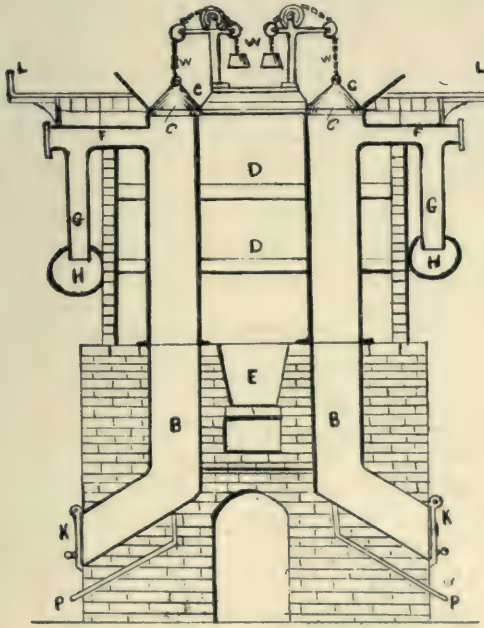

FIG. 42.—Hanmer's Distillation Plant.

the heated gases are caused to circulate. P, P are pipes for the the introduction of steam into the retorts.

Viola's Wood Distilling Apparatus.—Viola's apparatus (U.S. Pat. 767,090, 1904) consists of a cylindrical retort mounted on trunnions in a position slightly inclined from the horizontal, in which position it can be rotated and heated by a furnace. The retort, which is provided with a

stirrer, is connected at its lower and upper ends by means of air-tight joints with pipes of about the same diameter for removal of the products. The charcoal is drawn from the lower end of the retort into an upright receptacle, while the gases, tar, etc., pass off through the upper pipe to condensing and cooling arrangements.

Pritchard's Process of Wood Distillation.—The novelty in this process (U.S. Pat. 1,110,820, 1914) is that the wood is introduced into the heated retort in containers which are so constructed that there is an open space between the charge and the walls of the retort which prevents overheating of any parts of the latter. The gases are exhausted from the retort by means of a fan or other device, passed through a cooling plant, and the uncondensed gases are carried back to the retort, through which they pass and help to distribute the heat. In a second patent (U.S. Pat. 1,110,850, 1914) the gases are drawn from the retort by means of a fan, and are passed through a pipe into the open spaces above the charge without being cooled.

Blair, Campbell and McLean's Mechanical Retort.—Messrs. Blair, Campbell and McLean, Ltd., and J. K. Ross and E. P. Corner have devised a mechanical retort (Eng. Pat. 118,960, 1917) for the carbonisation of wood, applicable to sawdust, shavings, small wood and other carbonaceous products. The arrangement consists of a vertical retort in which are arranged a series of superimposed trays. A central shaft, provided with horizontal arms, is caused to revolve so that the arms sweep the trays. The material to be distilled is fed in at the top of the retort, and is caused to travel round the first tray by means of the revolving arms, passing through a slot into the tray below, and so on right through the series, finally passing out fully carbonised at the bottom. The gases and volatile materials evolved during the distillation pass up through an annular space around the central shaft to the exit at the top of the retort.

Uses of Pyroligneous Acid.—Impure acetic acid, known as pyroligneous acid, obtained by the destructive distillation of wood, can be used for a variety of purposes when colour and odour are not of much account. In addition to the preparation of crude acetate of lime, for which purpose most of it is employed, it is used in the manufacture of crude acetate of iron (pyrolignite of iron), which finds employment as a mordant in the dyeing industry. A new use has also been found for it as a coagulant for rubber latex, for which, according to B. J. Eaton and G. S. Whitby,[1] it is quite suitable, although the rubber separated by it is not such a good colour as when purified acetic acid is employed. The pyroligneous acid tried for this purpose was obtained by the distillation of the wood from the mangrove and rubber trees, both of which are local products of little or no value at present, and therefore all the more desirable from the point of view of economy.

Uses of Wood Tar and Oils.—In the separation by flotation of sulphide ores, preliminary trials made in the United States [2] with commercial wood oils obtained in the distillation of hard woods have turned out very satisfactory. Some of the products, indeed, gave results quite as successful as when pine oil was employed. It is also stated that crude hardwood tar, which separates from the pyroligneous acid, could be employed for the same purpose. Similar trials have also been made at Cobalt, Ontario,[3] in the separation of mineral ores, employing heavy hardwood creosote, acid creosote oil, and ketone residues, which are equally encouraging.

To facilitate the carbonisation of waste wood or sawdust in the Heidenstam process the dried material is first converted into briquettes.

[1] *Agric. Bull. Fed. Malay States*, 1917, p. 124.
[2] R. C. Palmer, G. L. Allen, and O. C. Ralston, U.S. Bureau of Mines, Amer. Inst. Min. Eng., September 1916.
[3] R. E. Gilmore and C. S. Parsons, *Can. Chem. Jour.*, 1917, pp. 151, 180.

As pointed out by Siermann,[1] in the distillation of wood refuse a resinous crust is gradually formed on the sides of the retorts, which interferes very considerably with the heating of the same. In order to obviate this difficulty Schneider uses a horizontal retort, which is caused to revolve in one direction, while a screw-worm conveyer, in the centre of the cylinder, revolving in the opposite direction, serves to carry the charge forward. The waste is fed in at the firing end of the cylinder, passing out as charcoal at the opposite end, from which it falls into two cooling chambers, which are used alternately. The material is first preheated on the top of the cylinder. The gases pass away by an opening at the centre of the cylinder. The capacity of a plant with a retort 3 metres long and 1 metre diameter was 570 kilos of sawdust and shavings of hard wood, *e. g.* beech, elm, oak, containing 24 per cent. of water, in three hours, the yield being 122 kilos of charcoal, and 241 kilos of liquid containing 0·24 per cent. of tar, 6·5 per cent. of acetic acid and traces of acetone and methyl alcohol. The fuel consumed amounted to 12 kilos of gas coke for heating the retorts, and 105 kilos of Westphalian coal for raising steam for the boiler.

Sawdust and small wood-waste, owing to their compactness when in bulk and their bad conductivity for heat, are best distilled in mechanical retorts, that is, in apparatus in which by mechanical means it is agitated or kept moving. Jas. C. Lawrence [2] mentions that there are two distinct types of mechanical retorts now in use, the horizontal and the vertical, the former being the most commonly employed. The horizontal retorts are variously constructed, one form being cylindrical and with a helical coil which conveys the material from one end of the retort to the other (*see* p. 82). A very usual form is oblong in shape, divided into an upper and lower compartment by means

[1] E. Siermann, *Chem. Zeit.*, 1901, p. 1158.
[2] Jas. C. Lawrence, *Jour. Soc. Chem., Indt.*, 1918, 5 T.

of a partition. Endless chains, carried on revolving drums at each end, are caused to travel across the upper chamber and then back along the lower chamber, and these, being provided with scrapers, serve to carry the charge along. The material is fed in at one end of the upper compartment, is carried by the scrapers to the back, where it falls into the lower compartment, and is brought again to the front and discharged in the form of charcoal fully carbonised. The exit pipe for the gases is of ample area, to prevent choking, and connects to condensers for the recovery of the tar and acetic acid, etc. A somewhat modified form of this retort has only one large chamber, in which the endless chain and scrapers pass backwards and forwards several times, so that the material undergoing carbonisation is raked over and over several times.

Of the vertical retorts the only one known to the author as being successful is the Ross and Corner's patent type. In this form the retort consists of a vertical metal cylinder tapering at the bottom in the form of a cone, from the apex of which the charcoal is delivered. The cylindrical portion of the retort is equally divided into a number of chambers by means of plates, which extend from the outer walls to within a small distance of the central shaft, thus leaving a circular opening for the escape of the gases. In each dividing plate there is an opening in the form of a slot. The central shaft is provided with arms, which extend over the plates at different heights almost to the outer casing. The wood-waste is fed in through a hopper at the top of the retort, and is carried round by the arms, which serve also to agitate it; as it reaches the slot it falls to the next compartment, where it is subjected to the same treatment, and so on right through the retort, in its descent being subjected to a gradually increasing heat, until finally it is discharged through the conical bottom fully carbonised. The slots in the dividing plates are, of course, not placed opposite each other, but are spirally arranged so that the

material may remain in each compartment the maximum length of time before falling to the next.

Mullers' Method of Treating Wood and Sawdust.—J. H. and A. Müller (Fr. Pat. 357,432, 1905) propose to steep the substance in a mineral acid, sulphuric acid being preferred. After this treatment it is distilled, and the vapours are passed through a red-hot iron tube. The inventors state that from 100 kilos of wood (containing 35 per cent. of water), after treatment with 20 kilos of sulphuric acid and distilling at a temperature rising to 160° C., there are produced, after rectifying 3 kilos of wood alcohol, 7 kilos of acetic acid, 2 kilos of oil of turpentine, and 40 kilos of dense wood charcoal suitable as a substitute for animal charcoal.

The distillation of wood in Russia previous to the war was an old and flourishing industry. Archangel pitch and tar were for many years well-known commodities, but they were made in a very primitive and wasteful fashion, and it is only quite recently that modern methods had begun to be introduced. Usually the wood was carbonised in large pits 10 to 16 feet diameter, which were excavated in the sloping banks of rivers. At the bottom of each pit was a funnel-shaped opening leading to a sloping trough, which communicated with a ditch on a lower level than the pit and some 20 or 30 feet away. The charge of wood was covered over with wet clay or earth, so that the liquid products of distillation passed downwards into the trough, and thence into a bucket placed in the ditch to receive them. The heat required for the distillation was supplied by the combustion of a part of the charge. Recently a considerable amount of stump wood left after clearing the woods has thus been treated in Western Russia, notably in the region of the River Vistula, and considerable quantities of pitch and turpentine have been supplied to Germany, the latter being in great demand there owing to its low price. At one time the shipments of wood tar

and pitch from Archangel to England amounted to 100,000 barrels per annum. The wood operated upon consists almost solely of pine, the most resinous portions only being chosen, *i. e.* the stumps and roots, the vertical roots being the richest in this respect, and these are left 10 to 20 years in the ground before being used. The production of wood distillation products in Russia was estimated to be 55,000 tons of pine pitch, 27,500 tons of tar, 2400 tons of rosin, and 964 tons of turpentine annually.[1]

Extraction of Turpentine and Rosin from Wood.—Owing to the growing scarcity of turpentine and rosin, by reason of the destruction of the trees from which they are obtained, attention has been for some time directed to the treatment of the waste wood for their extraction.

Numerous processes have been devised and patents taken out for the extraction of this waste wood, some of which have been successful, but these are only applicable to highly rosinous wood, such as pine; hard woods, such as beech, oak, etc., do not yield any of these products, and must therefore be submitted to the usual destructive distillation in retorts; even in the case of rosinous woods only certain portions of the tree, as, for instance, the "light wood,"—*i. e.* the cores of the trunks left after tapping for turpentine, and the stumps and roots—being sufficiently rich in turpentine to render the operation remunerative, the great bulk of the wood and the sawdust from lumber-mills offering no inducement from a monetary point of view.

A considerable amount of information on this subject is given by J. E. Teeple, Ph.D.,[2] who stated that at the time of writing (1907) there were in the United States some 80 plants in operation for the extraction of turpentine from "light wood" and from mill waste. Among these he was fairly familiar with the operations in 50,

[1] *U.S. Comm'l. Rep.*, No. 191, August 16, 1915.
[2] J. E. Teeple, Ph.D., *Jour. Soc. Chem. Indt.*, 1907, 811.

and had an intimate knowledge of the working of 12 to 15, so that his experience is somewhat extensive. He states that when a tree is wounded, a large number of rosin ducts immediately form in the surrounding tissues, the exudation from which gradually plugs up the wound, thus acting as a natural protection to the tree. In tapping for turpentine over a number of years these accumulations become so extensive that the whole trunk of the tree, up to a height of about 10 to 15 feet, becomes thoroughly imbued with the rosinous material, which differs from the liquid which has been tapped away only by the greater percentage of rosin, and the lesser proportion of turpentine which it contains. When the tree decays this "light wood" remains for a long period, since it is scarcely altered by exposure, and in some districts large quantities of it are available, and are now being worked up. The name "light wood" has been applied not because it is ponderably light, since it is very heavy, weighing from 4000 to 5000 lb. per cord, but because it is used by the negroes for lighting their fires and for torches. It has also been known for some time that pine stumps and roots from felled trees are very rich in turpentine and rosin; these were first utilised for the production of tar by distillation, and many attempts were made to extract the turpentine from them, but not with much success. The first patent for this purpose was taken out in 1841, but the operation did not become a commercial success until 1872, when a plant was built at Wilmington, N.C. The products obtained in the destructive distillation of "light wood" and stumps are essentially the same as those yielded by the distillation of hard wood, *i. e.* acetic acid, wood alcohol, gas, tar, and charcoal, but, in addition, 6 to 30 gallons of spirits of turpentine were obtained, according to the richness of the material in rosinous substance. The yield of wood alcohol, however, is practically negligible, *i. e.* only 1 to 2 gallons per cord, as against 10 gallons from

hard wood, the recovery of which would not pay for the labour, and this item is, therefore, in most cases left out of account. The acetate of lime is also less in quantity and of poorer quality than that from hard wood, being that quality known as "brown acetate," which is quoted at a lower price in the market than is the "grey acetate" from the distillation of hard wood. As an offset against this, however, the yield of wood tar is very considerable, and this, being of the quality known as "pine tar," is much more valuable than the ordinary wood tar, and is in very good demand. On distillation it yields pitch and creosote oils, the latter being extremely useful for creosoting timber, for the manufacture of disinfectants, sheep dips, timber stains, etc., while the pitch is also in good demand for caulking wooden ships, brush-making and the like. Besides these two products it also yields "wood oils," which are employed in the essential oil and drug industries.

Many of the original plants for the destructive distillation of "light wood" and other waste have been abandoned from different causes. As a rule the yield of turpentine did not come up to expectations, and, moreover, it was so contaminated with the products of decomposition that a remunerative price could not be obtained for it, and, although it could be very much improved by chemical treatment, the losses entailed in the process were very considerable.

The problem of the recovery of turpentine from pine waste other than by direct fire heat has occupied much attention, and many patents have been taken out for different appliances and methods. Among the first of these was the use of a jacketted retort, the jacket being filled with a high-boiling-point oil or melted rosin, through which the heat was applied to the interior from an external fire, but this was further extended in 1865 by a patent granted to Johnson for filling the retort itself with the material, which then conveyed the heat directly to the

wood. According to Teeple there are at present at leas three plants operating on this system, modifications o which have been patented several times within recen years.

The method usually followed is, after charging the retor with wood, to pump in melted rosin until the latter i entirely covered with it, and pass in superheated steam t keep the rosin at a sufficiently high temperature.

The steam passing out of the retort carries with it th spirits of turpentine, which is recovered by passing throug a condenser, together with more or less wood oil and som rosin oil produced by the decomposition of the rosin. I is therefore necessary to separate these from the turpen tine by fractional distillation. It has been claimed tha as much as 30 gallons of turpentine and 40 gallons o heavy oil and rosin oil are obtainable by this proces but according to the above-named authority the averag figures may be taken as 12 to 15 gallons of turpentine 2 to 3 gallons of heavy oils, and 5 gallons of rosin oils The operation is somewhat expensive, seeing that a certai proportion of the rosin is lost in the wood, besides whic there is a considerable danger of fires occurring.

Essentially the process is one of distillation with super heated steam, in which the rosin acts the part only of conductor of heat, and might therefore be dispensed wit and its cost saved by using superheated steam alone Many patents have been taken out in this connection the first being granted to Hull in 1864, and at least si plants are working on this system at the present time It is problematical, however, whether any advantage i gained by superheating the steam. Usually the wood i ground small and charged into a large vertical retor through which the superheated steam is passed, comin into direct contact with the wood, carrying with it th turpentine and other oils into a condensing plant. I suffers from the disadvantage that the wood in the proximit

of the steam inlet becomes, to a certain extent, charred, the volatile products from the decomposition imparting to the turpentine a disagreeable odour which requires very careful purification for its removal.

The simplest method of distillation appears to be with steam which has not been superheated, the first patent in which this is mentioned being that of Leffler, granted in 1864, which, however, did not at the time receive any notice, but only came into prominence many years later when it was claimed by Krug. Numerous patents have since been taken out for modifications of the method or the plant. All kinds of devices have been tried: horizontal retorts charging in at one end and discharging at the other, vertical retorts charging at the top, discharging below, mechanical devices for charging and discharging retorts mounted on trunnions discharged by simply inverting, charging the wood into baskets which are placed in the retorts, also into cars run into horizontal retorts, and also retorts in which charging and discharging can be done continuously. Numerous methods of applying the steam are also claimed: at the top of the retort, at the bottom, at the side, at different levels, and so on; the utility of some of which has never been fully established. According to the method, however, the time of steaming may occupy from 1 to 12 hours to extract the turpentine, and the yield varies from 6 to 25 gallons per cord, or an average of 12 to 15 gallons per cord, according to the richness of the "light wood" and the efficiency of the plant employed. The spirits of turpentine obtained by this method, after being refined, which is not a difficult operation, boils between the limits for "gum" turpentine, and fulfils all the requirements for this article required on the market.

None of these processes attempt the extraction of the rosin from the wood, but the residue in the retorts may either be subsequently destructively distilled in another

retort, which is difficult, owing to its physical condition rendering it a very poor conductor of heat, or it may be used to some extent as fuel, but wherever possible it should be converted into pulp for paper-making purposes, since it can be used in the manufacture of low classes of paper.

G. B. Frankforter [1] states that in felling trees usually not more than 40 per cent. of the wood is utilised, and from the statistics published for the year 1907 this would mean 150 million tons of waste wood produced in the United States. Samples of Norway pine and Douglas fir stump wood were extracted with solvents, lean wood yielding 4 to 6 per cent., average wood 14 to 16 per cent., and very rosinous wood as much as 43 to 46 per cent. of oleo-resin, but the trunk wood from the same trees contained much smaller quantities. The oleo-resin extracted from the above-named woods yielded on distillation 78 per cent. of rosin and 22 per cent. of turpentine. Frankforter is of opinion that at least one-fifth of the total waste could be used for distillation, and recommends for this purpose a still, consisting of a "cordate" tube set in a furnace in such a manner that the heat is graduated from bottom to top, with continuous feed and discharge. The yield of useful products is increased by making several holes in the upper part of the retort, through which the oleo-resin can flow out and thus escape decomposition.

In practical trials with three species of fir the yield of products was as follows: charcoal, 22 to 24, gaseous products, 24 to 26, tar and terpenes, 14, and pyroligneous acid and water, 37 to 38 per cent. on the weight of the wood taken. The wood tar is, in many cases, difficult to dispose of, and much of it is burnt under the stills, while the pyroligneous acid is so weak that it is run to waste. The waste can, however, be better utilised by first heating it with superheated steam, which carries off the whole of the turpentine, leaving the rosin behind, which may be

[1] *Jour. Ind. and Eng. Chem.*, 1911, 4.

extracted with a volatile solvent. The author has had very successful results with a battery of extraction vessels in which the wood is treated with light petroleum or coke oven benzene heated by a boiler, so that it distils over on to the wood and dissolves the rosin, and then percolates back to the retort. After the extraction the rosin is recovered by evaporation of the solvent, while the wood in the retort is treated with a current of air and steam to remove the last of the volatile solvent. The wood is finally converted into pulp by heating with alkalies in the extraction vessel, the yield of pulp varying from 16 to 43 per cent. on the original material according to its quality, which may be sawdust, stumps, roots, and branches.

According to the *Oil, Paint and Drug Reporter* (Oct. 16, 1911, p. 53), a considerable amount of the rosinous wood-waste in the Douglas fir belt, west of the Cascades in Washington and Oregon, is distilled in retorts. The wood is first sawn into small blocks, not more than 6 inches long and 2 inches diameter, and is first distilled in a current of steam for 6 to 8 hours, during which the temperature gradually rises to 325° F., and the whole of the turpentine has passed over. After shutting off the steam fire heat is applied until carbonisation is completed. The gas is scrubbed and then burnt under the stills. One cord of Douglas fir-waste yields 4 to 12 gallons of turpentine, 150 gallons of pyroligneous acid, 12 gallons of tar oils, 20 gallons of tar, 200 to 400 lb. of pitch, and 800 lb. of charcoal, and from one cord of stump wood were obtained 8 gallons of turpentine, 20 gallons of tar oils, 35 gallons of tar, and 42 bushels of charcoal.

G. Walker [1] points out the many obstacles to profitably distilling the waste from saw-mills, which consists of slabs, edging, and sawdust; these parts of the tree of soft wood yielding only small amounts of methyl alcohol, acetic acid, and tar; and, moreover, the charcoal is of the

[1] G. Walker, *Jour. Soc. Chem. Indt.*, 1911, 934.

friable kind, and mostly in such small pieces that it is of but little value except for burning under the stills. The case is, however, different with the waste from hard wood, which, distilled under proper conditions, should yield practically the same quantities of products as are obtained in the hard wood distillation plants in New York and Pennsylvania in which beech, birch, and maple are the raw materials. Then, again, with regard to the extraction of turpentine. This can be profitably obtained only from the waste from long-leaf yellow pine, and from those trees which have been " boxed " for turpentine—either the " light wood " or the logs in which the " box " faces have been cut and which are heavily encrusted. Walker has distilled a considerable amount of " light wood " at a works in South Carolina. The retorts were cylindrical in form, constructed of steel, and were arranged for both steam and fire heating. After charging the retorts a small fire is made and steam passed directly through the charge until the turpentine has distilled over. The current of steam is then discontinued, and the heat raised, whereupon the heavier oils pass over. The distillation is continued until the material is completely carbonised, then the water in the condenser is run out, and steam blown through the apparatus with the double object of damping the charcoal, and thus preventing it taking fire when it is discharged, and of freeing the condenser from the heavy oils which would otherwise contaminate the next batch of turpentine and render it much more difficult to purify. During the distillation a steam jet exhauster attached to the exit end of the condenser produces a partial vacuum in the apparatus, thus quickly evacuating the fumes from the still, and preventing undue decomposition of the volatile products. The uncondensable gases are forced through a purifier containing wire gauze screens, which arrest the tar spray, and from this the purified gases pass through pipes to the furnaces, where they are burnt.

Also at a works at Conway, South Carolina, in 1905, there was installed a plant for the extraction of rosin from waste wood which has proved very successful, and is producing at least 200 barrels of rosin per week. In this plant the wood, in a finely comminuted state, is first heated by open steam for the removal of the turpentine, and is then extracted with a volatile solvent for recovery of the rosin. Walker states that this plant will produce in 12 hours five times as much rosin and turpentine as could be obtained from the same quantity of wood in 4 years by the old method of "tapping" or boxing, and he is therefore of opinion that in the near future this method of extraction will be used in preference to the older process, which is extremely wasteful. Another advantage in this method lies in the fact that the wood after extraction is very suitable for conversion into wood pulp.

A considerable amount of "light wood" is used for railroad ties, but after allowing for this, competent authorities are of the opinion that there is enough "light wood" left in the Southern States to supply the whole world with turpentine and rosin for a number of years.

L. F. Hawley and R. C. Palmer[1] state that the distillation of the wood of the long-leaf pine with steam has been in operation in America since 1903, the object being to utilise the saw-mill waste and "light wood." This process yields a turpentine which is free from the objectionable products of destructive distillation, and is therefore of better colour and odour, but unfortunately it is, according to them, the only product of value, and not more than 15 plants were operating it in 1911. In their experiments in a small copper still they found, with finely divided material like sawdust, steam at ordinary atmospheric pressure was not successful in completely removing the turpentine, although steam at 40 lb. pressure was capable

[1] *U.S. Dept. Agric. Forest Service Bull.*, 109, 1912, p. 31.

of doing so. When chips were employed even steam at 70 lb. pressure did not remove the whole of the turpentine, but somewhere about 80 to 85 per cent. The authors feel that this process could be made successful if the wood is subsequently treated for the extraction of the rosin.

Experiments described by H. C. Chute [1] on the destructive distillation of "light wood" in a retort 9 feet long and 5 feet diameter which held a cord of wood, resulted in the production in 36 hours of 110 gallons of oil and tar, 150 gallons of pyroligneous acid (equivalent to 100 lb. of grey acetate of lime) and 500 lb. of charcoal. The oils yielded 16 gallons of wood turpentine, boiling between the limits for "gum" turpentine, and, in addition, 4 gallons of wood alcohol. In another retort, holding several cords, the "light wood" yielded by steam distillation 10 gallons of oil, only 6 gallons of which boiled between the limits for "gum" turpentine. Mill-waste under similar conditions yielded only 2 gallons of turpentine, which is explained by the fact that ordinary mill-waste is mostly composed of comminuted sap wood which contains but little rosin.

A. Luttringer [2] states that a process has been operated in France for the treatment of larch stumps for the manufacture of turpentine, rosinous products, and wood pulp. The wood contains about 30 per cent. of substances soluble in ether, and is treated in such a manner that the desired result is obtained in one operation.

The wood is charged into a digester, in which it is treated at 5 to 7 atmospheres pressure with a solution consisting of: sodium hydrate and sodium sulphide 60 to 100 kilos, sodium carbonate 30 kilos, sodium sulphate 50 to 200 kilos, and water 1500 to 1800 litres, the operation extending from 6 to 12 hours.

While the digestion is proceeding a slight escape of

[1] H. C. Chute, *Jour. Soc. Chem. Indt.*, 1912, 421.
[2] A. Luttringer, *Papierfab.*, 1913, 884. Also *Soc. Anon. Le Camphre*, French Pats., 462,681, and 463,869, 1912.

steam is allowed to pass through the pipe at the top of the digester into a condenser, by which means the turpentine is distilled over and condensed. As soon as oily drops cease to flow from the end of the condenser the valve is closed, and the digestion continued for the requisite length of time. After the completion of the digestion the lye containing the rosin in suspension or solution is run out of the digester into an evaporator, in which it is concentrated, the liquid being carried to dryness and the residue destructively distilled, yielding methyl alcohol, acetone and tar, from which latter rosin oils, phenols, etc., may be separated by the usual means, while the residue is again used in a subsequent operation.

The products yielded by 1000 kilos of larch stumps are stated to be: wood pulp 315, oil of turpentine 59·9, pine oil 11·3, pinolin (rosin spirit) 13·8, light rosin oil 8·7, ordinary rosin oil 60, oil containing retene 9·2, solid retene 24, wood alcohol and acetone 5·8, phenols 15·7 kilos. The total value of the products from 1 ton of stumps was at that time valued at £6 8*s*.

A few of the more recent patents for the extraction of turpentine and rosin from waste wood may be mentioned.

In the patent specification of J. C. Mallonee (U.S. Pat. 766,717, 1904) claim is made for the use of a retort which is heated internally by a perforated steam coil and also externally. It is stated that by this means three fractions of oils are obtained, the specific gravities of which are respectively 0·855 to 0·92; 0·92 to 0·96, and 0·96 to 1·00 or above.

C. E. Broughton (U.S. Pat. 771,706, 1904) employs, firstly, superheated steam under pressure at a temperature of 300° F. for the removal of the turpentine oils without decomposition. Fire heat in addition to the steam is then applied, the temperature being 450° to 500° F., whereby heavier oils are produced and collected in fractions as may be required. Finally, when the distillation becomes

sluggish, the steam is cut off and external heat only employed, yielding at temperatures up to 800° F. creosote and tar oils, which are separately collected. The accumulation of tar in the retort is drawn off through a tap at intervals, until finally charcoal alone remains in the still.

The use of superheated steam is also claimed by C. B. Darrin (U.S. Pat. 839,119, 1906), the temperature rising to 340° F., the products being collected and separated according to their gravities. After steaming, the wood is subjected to external heat for extraction of the tar and pitch. The lighter oils are purified and decolorised by redistillation at 320° F.

M. McKenzie (Fr. Pat. 367,926, 1906) extracts the turpentine by heating the wood in a still along with rosin, rosin oil, hydrocarbon, or other oils. The oil of turpentine distils over, and may be rectified by the usual processes, while the oil employed in the still is run out and used for treating further batches of the material.

A similar method is claimed by F. A. Kunmer (U.S. Pat. 984,818, 1911), rosin oil being used as the conductor of heat.

H. T. Yaryan (U.S. Pat. 915,400, 1909) proposes to extract the wood with a volatile solvent, which removes both the turpentine and the rosin. The turpentine and the solvent are then separated from the rosin by distillation, and by a second distillation with a rectifying column and a condenser the turpentine is obtained free from the volatile solvent.

H. T. Yaryan (U.S. Pat. 992,325, 1911) also claims the use of steam, with or without the help of a partial vacuum, for obtaining the turpentine. The rosin is then extracted by a hot hydrocarbon solvent, which is distilled off, leaving the rosin with some turpentine behind. The residue is then further heated for recovery of the turpentine which it still contains. The solvent left in the wood in the still is driven off by again passing steam through the material.

In the patent granted to W. B. Harper (U.S. Pat. 1,085,416, 1914), claim is made for a method of extracting turpentine and rosin from wood. First the wood is subjected to the action of low-pressure steam to remove the turpentine. The oils are then distilled over in a current of high-pressure steam, the temperature of which is insufficient to cause the decomposition of the wood or rosin which it contains. Finally, the wood is treated with a hot hydrocarbon solvent for extraction of the rosin, which is obtained by distilling off the solvent.

With regard to the extraction of rosin from waste wood patents have been granted for quite a number of different solvents. Thus F. Pope (U.S. Pat. 852,078, 1907) claims the use of a mixture of pine tar, heavy residuum of wood extraction, and pine oil. C. P. Ogilvie (Eng. Pat. 5978, 1909) depends on the use of the "light" oils which are obtained from wood, which can be separated from the heavier oils and rosin by distillation and used again. J. H. Castona (U.S. Pat. 1,111,644, 1914) uses turpentine, which can be recovered from the rosin, and will be augmented by that which is extracted along with the latter. T. S. Clope (U.S. Pat. 1,144,171, 1915) specifies as a solvent that portion of the distillate from coniferous woods which distils between 170° C. and 185° C., and has a specific gravity between 0·875 and 0·880, or other solvent consisting mainly of limonene, dipentene, and cineol. J. Frydmane (Fr. Pat. 476,330, 1914) claims the use of that fraction of the white spirit, or "sangajol," boiling between 80° and 140° C., which is separated by fractional distillation from the petroleum of the Dutch Indies. This dissolves both the turpentine and the rosin. The solvent and the turpentine are separately distilled off from the rosin by fractionation. W. M. Bashlin (U.S. Pat. 1,059,261, 1913) claims in his patent the use as a solvent of a mixture of 1 part of turpentine and 4 parts of benzol.

M. C. Whittaker and J. S. Bates (U.S. Pat. 1,142,922

1915) rely on caustic soda as a solvent for the rosin, the latter being separated from humus in the form of a rosin soap by the further addition of very strong caustic soda solution. The alkaline solution, after separation of the rosin, can again be used for pulping more waste wood.

CHAPTER IV

MANUFACTURE OF ILLUMINATING GAS FROM SAWDUST

The production of illuminating gas from wood is a process of dry distillation; as we have seen, this process yields acetic acid, tar, and charcoal, together with gases which consist of carbon dioxide and monoxide, but possess little illuminating power if the distillation is carried on slowly. If, on the contrary, wood is rapidly heated to a high temperature, the greater part of the volatile products undergoes decomposition, and hydrocarbons are formed which are partly liquid and partly gaseous. By rapid distillation wood yields large volumes of gas, which is easily purified, and possesses very considerable illuminating power; charcoal, tar, and small amounts of acetic acid being obtained as subsidiary products. The retorts are similar to those used for the distillation of coal; they must be filled with wood (sawdust, refuse, etc.) only to one-third of their capacity. The retorts should be at a full red-heat before the wood is charged in, and the charging must be performed as rapidly as possible, large volumes of gas being evolved at an early stage of the distillation. The time required for working off a charge is 75 to 120 minutes. In consequence of the rapid decomposition of the wood a certain amount of pressure is developed in the retorts, which, however, is rather an advantage, as it keeps the tar-vapours somewhat longer in contact with the hot walls of the retorts and promotes their decomposition. In the gas-works of H. Walker at Deseronto (Ontario) illuminating gas has for some time been manufactured from sawdust, while similar wood-gas plant is at work in other

localities, and is employed for illuminating the workshops. As raw material, well-dried pine-wood sawdust is used, which yields 20,000 to 30,000 cubic feet of gas per ton. The retorts used are similar to those ordinarily employed for making coal-gas; the process of purification is, however, not the same, since the impurities in wood-gas are different from those obtained from coal. Sulphuretted hydrogen and ammonia, which are the chief troubles of the coal-gas manufacturer, are almost entirely absent from wood-gas. Rosinous wood is, of course, preferred to other woods for the manufacture of wood-gas, as it not only gives a larger volume, but yields gas of higher illuminating power. In the works mentioned above, the drying of the sawdust, which is one of the most essential conditions of a well-organised gasification, as well as the further preparation of the raw material, is carried out almost entirely by mechanical appliances. In localities where sawdust can be cheaply obtained, and where there is a demand for the by-products, such as charcoal, wood-tar, wood-vinegar, etc., the manufacture of wood-gas is able to compete advantageously with that of coal-gas.

The crude wood-gas contains very considerable amounts of carbon dioxide, which it is necessary to remove, since the presence of this product markedly diminishes the illuminating power of the gas. Since this, however, can only be effected by the use of lime, and since 1000 cubic feet of gas require 66 to 77 lb. of lime, the cost of the gas is thereby materially enhanced. The lime in the purifiers combines also with the creosote, and with any acetic acid which has not been condensed in the coolers. The amount of creosote absorbed is but small, since its compound with lime is decomposed by carbonic acid.

Two cwt. of wood yield—

Gas	1200 to 1400 cubic feet.
Pyroligneous acid	1 to 1¾ lb.
Tar	4½ lb.
Charcoal	33 to 44 lb.

Where wood-waste is plentiful, and no very great use can be found for it, the manufacture of gas is a proposition well worth considering, but the extreme bulkiness of the material and the formation of acid products on distillation, which destroy the iron pipes and connections, are serious drawbacks to its employment for this purpose. G. Walker [1] mentions a town in Canada where waste wood is employed for the manufacture of illuminating gas, the plant consisting of two benches of five retorts in each, capable of dealing with 10 tons of sawdust per day. The retorts were of cast iron, 12 feet long and 2 feet in diameter, the thickness of the metal being $1\frac{1}{2}$ inches. Each retort was provided with an Archimedian screw, which received the sawdust from a hopper, carried it right through the retort, and delivered it by means of an opening in the further end into an air-tight sheet-iron car. The sawdust was produced from Canadian pine, and was dried in a preliminary heater before delivery to the carbonising retorts. Since the special object of this plant was the production of illuminating gas the other products of the distillation, which were insignificant in quantity, were not in any way utilised.

It may be mentioned, as pointed out by Dr. C. A. Doremus,[2] that in Wilkinson's process for the production of gas from cord wood [3] in stationary retorts, in order to obtain as high a yield of gas as possible and also with a view to destroying the acid products as much as is practicable, part of the wood after carbonisation is pushed to the back of the retort, so that the gases containing steam, acid, alcohol, etc., which are generated during the carbonisation must of necessity pass through a column of red-hot charcoal, which serves to destroy the organic matter and also to produce a certain proportion of water-gas.

Owing to the great shortage of coal during the last few

[1] G. Walker, *Jour. Soc. Chem. Indt.*, 1911, 934.
[2] C. A. Doremus, *ibid.*, 1911, 730.
[3] *Jour. Amer. Chem. Soc.*, 1880, 449.

years, in several countries it has been necessary to employ wood, either alone or in admixture with coal, for the manufacture of gas.

In the municipal gas-works at Horsens, Denmark,[1] in 1917, both wood and peat were carbonised, the latter after it had been air-dried in stacks. A proportion of coal was also carbonised, but in separate retorts. The retorts are hand-fired, horizontal ones, the charge being 55 to 60 kilos of wood or peat, and the yield of gas was 30 cubic metres per 100 kilos. The latter contained 23 to 25 per cent. of carbonic acid, and had a gross calorific value of 3700 to 4000 kilogram calories per cubic metre. Difficulties occurred due to the accumulation of pitch in the hydraulic main, and there was an increased number of naphthaline stoppages. The gas contained very little ammonia, but an admixture of coal yielded sufficient ammonia to neutralise the acid present, and thus prevent its action upon the iron plant. An increased consumption of gas was noted, and the air-supply of gas stoves needed adjustment, but no other difficulties attended its use. The pitch from the wood-tar was stated to be valueless, but the brown tar was readily disposed of; the wood charcoal also could be used in suction gas producers, but the char from peat had little value, since it was very small and impure; it was sold as a second-rate fuel for household and industrial uses.

According to A. Molin [2] approximately one-half of the gas now supplied in Stockholm is manufactured from wood, which is carbonised in inclined retorts. The yield of gas is about the same as that from coal, *i. e.* about 600 cubic metres per ton, but its calorific value is lower, *i. e.* 3000 to 3300 kilo-calories per cubic metre. The charge for each retort is 50 kilos every two hours. A small quantity of coal, equal to about $\frac{1}{10}$th the weight of the wood, is added

[1] *Jour. Gasbeleucht.*, 1918, 193.
[2] A. Molin, *Jour. Gasbeleucht.*, 1918, 55.

to each charge to increase the proportion of heavy hydrocarbons, so that by their decomposition a deposit of carbon may be produced on the retorts, which serves to keep them gas-tight, and also to furnish sufficient ammonia to neutralise the acetic acid which escapes decomposition. In order to reduce the proportion of carbonic acid in the exit gases, about half the previous yield of charcoal is left in the retorts over which the gases have to pass, and by means of which a proportion of the carbonic acid is converted into carbonic oxide. In the early stages of the distillation, however, there is a violent evolution of gases, so that much carbonic acid escapes unaltered, and this requires a considerable amount of lime in the purifiers for its removal.

From the *Times Engineering Supplement* for October 29, 1913, we learn that, in a paper read before the Victorian Gas Association, the use of wood in admixture with coal for gas-making was referred to, and the statement was made that it was thus employed in Australia in proportions up to 25 per cent. For this purpose box and red gumwood are regarded as most suitable, the yield of gas being about 12,000 cubic feet per ton with a calorific power of 450 B.Th.U. The use of wood had two distinct advantages, since it prevented the deposition of naphthalene in the pipes, and also gave very little deposit of carbon in the retorts.

In Switzerland, owing to the shortage of coal, wood and peat are now being employed in very considerable quantities in the manufacture of gas. The process, which is attributed to M. Demolis, of passing the gas over incandescent charcoal for the removal of some of the carbonic acid and the destruction of the acetic acid, is being perfected. Thus it is stated[1] that at Geneva sawdust in the proportion of 10 per cent. is added to the usual charge, which is carbonised in Bueb vertical retorts. Wood and coal are also alternately carbonised in two benches, the

[1] *Jour. de Usines à Gas*, 1917, 115.

gases being mixed, the tar produced not being acid. In this case the charge of wood is 260 lb. of logs, cut to 3 feet lengths, in place of 1,240 lb. of coal, and the amount of fuel required for carbonising is increased 25 per cent. The yield of gas varies from 8,570 to 8,830 cubic feet per ton. At the works of La Chaux-de-Fonds, Neuchâtel, sawdust is carbonised in horizontal retorts 14 feet 8 inches long, the charge being composed of 375 lb. of sawdust and 66 lb. of coal, as compared with 990 lb. when coal alone is used, the time required for carbonisation being 6 hours. The gas has a calorific power of 4,200 calories. Difficulties have been experienced owing to the high percentage of moisture in the wood, which amounts to 30 per cent.

At Neuchâtel wood is also carbonised, the proportion being about 28 per cent. that of the coal. The retorts are horizontal, 9½ feet in length, the charge being from 150 to 210 lb. of wood, and the time required for carbonisation 4 hours. The yield of gas is 10,600 cubic feet per ton, with a calorific power exceeding 4,300 calories. The wood and coal are carbonised alternately.

In France, at Arcachon, Gironde, heath roots have been tried for gas-making. They yielded 23·78 per cent. of gas and 22·84 per cent. of charcoal by weight. The charge amounted to 130 to 165 lb., which was carbonised in 2½ hours. It is stated that the charcoal is superior to that from pine wood, which is doubtful, and that the gas is of satisfactory quality.

Investigations have been made in France by a Committee appointed by the Society Technique du Gaz [1] into the merits of wood for gas-making. As a result of their labours they came to the conclusion that none of the materials could be regarded as suitable substitutes for coal except under abnormal conditions. Wood-gas has a higher specific gravity than coal-gas, requires wider slits

[1] *Jour. des Usines à Gaz*, June 20, 1916.

in flat flame burners, contains a high percentage of carbonic acid, needing much lime for its removal, and also contains acids of the fatty series, *e. g.* acetic acid, etc., which attack the iron of the condensers and other parts of the plant.

Irminger[1] has conducted numerous experiments on the distillation of different woods (fir, spruce, birch, beech, and oak) in the model retorts used at gas-works for testing coals at temperatures of 600° and 700° C. At the higher temperature the gas was more abundant, and it had a lower gravity, but its calorific power was higher, due to the lesser proportion of carbonic acid which it contained, and also to the greater proportions of hydrocarbons. The amount of pyroligneous acid was about the same in both series of experiments, but oak, beech, and birch yielded the greatest amount, the last two particularly. Wood spirit is present only in traces in the distillate from fir, but is found more particularly in that from oak and beech. Brushwood and cones can be distilled for the manufacture of gas, but the charcoal is of little or no value. In the distillate from very rosinous woods turpentine (wood turpentine) is found. This boils for the most part at 180° C., but much of it distils over before this temperature is reached.

From 1000 cubic feet of fir wood introduced into a red-hot retort (temperature 1,100° C.) were obtained 7,600 cubic feet of gas, having a calorific value of 460 B.Th.U. per cubic foot. The crude gas cannot be used for illuminating purposes except with a Welsbach burner. In this way it gave a light of about 36 candle power, with a consumption of 3 cubic feet of gas per hour. It can, of course, be used economically by burning under the retorts. There is in that case no advantage in distilling the wood at such high temperature, as the yield of the other useful products, acetic acid and wood spirit, is materially lessened.

[1] Irminger Ingeniren, Copenhagen, 1899, 311, *Proc. Inst. Civil. Eng.*, 1900, 49.

CHAPTER V

MANUFACTURE OF OXALIC ACID FROM SAWDUST

This technically important substance was first obtained in 1773 from salt of sorrel (acid potassium oxalate) by Savary. Oxalic acid does not appear to exist in the free state in nature, but occurs in combination with potash as acid potassium oxalate, and in combination with lime as calcium oxalate which is present in many plants.

At one time oxalic acid was manufactured by the very costly process of oxidising sugar with nitric acid, but at present it is made from cheaper organic substances without the use of nitric acid. Among these organic substances sawdust is the most important, in consequence of the abundance of the supply and the low cost of this material.

1. Soda Lye Process.—To prepare oxalic acid, 30 to 40 parts of sawdust are mixed with soda lye of specific gravity 1·35, containing 100 parts of actual alkali, and the mixture is heated in shallow pans to evaporate the water. The temperature to be employed is variously stated at from 175° to 240° C., but the higher of these temperatures should not be exceeded, as in that case the oxalate of soda would be decomposed into carbonate. As soon as particles of wood can no longer be seen in the mass, the fusion process may be considered finished, and the mixture is allowed to cool. The product contains sodium oxalate and carbonate, together with substances of the nature of humus, and the excess of the alkali originally employed. The mass is lixiviated with the smallest possible quantity of cold water, taking care that the solutions which are run off are not weaker than 35° Bé. By this operation the more

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readily soluble salts are dissolved, whilst the sodium oxalate is left as a residue. Another method is to dissolve the mass completely in the smallest possible quantity of boiling water, dilute the solution to 38° Bé., and allow to cool. Sodium oxalate crystallises out, and can be freed from the mother liquor by a centrifugal hydro-extractor.

The crystallised sodium oxalate is redissolved in boiling water and mixed with milk of lime in an iron vessel which is fitted with a mechanical stirrer. By this means it is converted into calcium oxalate and sodium hydroxide (caustic soda). To avoid an injurious excess of lime, the amount of quicklime for each operation is calculated and slaked. The greater part is added slowly to the boiling solution of the sodium oxalate; during the addition of the remainder, samples are tested at short intervals by filtering, supersaturating with acetic acid and adding calcium chloride. As long as this produces a precipitate or turbidity, indicating that sodium oxalate is still present, the addition of the milk of lime is continued. The precipitate of calcium oxalate is then allowed to subside, and the supernatant soda lye is drawn off and used for another melt, so that no waste of the caustic alkali takes place. The calcium oxalate is repeatedly washed with water; the washings being concentrated to recover the contained alkali, or may be used for lixiviating. The calcium oxalate has now to be decomposed, for which purpose it is mixed with water to the consistence of a thin pulp, heated by steam in a lead-lined vessel, and treated with sulphuric acid (15° to 20° Bé.), steam being meanwhile passed through the liquid until it boils. The amount of sulphuric acid to be used depends upon the amount of lime which has been required for decomposing the sodium oxalate, 56 parts of quicklime (calcium oxide) requiring 98 parts of sulphuric acid (H_2SO_4) for conversion into calcium sulphate. If to 1 part of lime there be taken 2 parts of sulphuric acid (66° Bé), or an equivalent quantity of a

weaker acid, this will give an excess which will advantageously assist the decomposition. The oxalic acid solution is now decanted from the precipitated calcium sulphate, the precipitate is repeatedly stirred up with water and finally is passed through a filter or filter press to recover the adhering solution. A sample of the precipitate is thoroughly washed with water, treated again with sulphuric acid, and tested with potassium permanganate for oxalic acid. If the warm solution decolorises the permanganate, oxalic acid is still present, therefore the precipitate requires a further treatment with sulphuric acid. The solution of oxalic acid is evaporated in a shallow lead pan. When the liquid reaches a specific gravity of 15° Bé. the evaporation is stopped, and the liquid is left to cool in order to allow the calcium sulphate, which was present in the weak solution, to settle down. The liquid, separated from the precipitate, is further concentrated in a second pan to about 30° Bé., and then run into shallow lead-lined wooden crystallisers. The degrees of concentration here mentioned must only be regarded as approximate, since they require to be modified according to the temperature of the room in which the crystallisation is to take place. Thus, in winter the first concentration must be stopped at 10° Bé., otherwise oxalic acid would crystallise along with the calcium sulphate.

The mother liquor is separated from the crystals by a centrifugal machine; it contains sulphuric acid, and can be employed in the next decomposition of calcium oxalate. The remainder of the mother liquor is removed by dissolving the crystals in a little boiling water and recrystallising.

Considering the relatively high cost of the alkali used, it is important to use the caustic lyes repeatedly; they are, however, highly contaminated with organic matter, from which they must be freed by evaporation and calcination. If, however, the lyes are merely evaporated and calcined, the organic matter will not be completely destroyed,

however high a temperature may be employed, since the alkali fuses and protects the organic matter from the action of the air. It is better to operate as follows : The liquor is concentrated to 40° Bé. (sp. gr. 1·386), and then mixed with enough sawdust to absorb it completely. The mass is then calcined in thin layers, either on iron plates or in a reverberatory furnace, until a sample extracted with warm water gives only a faintly coloured solution.

The greyish-black calcined mass is a mixture of charcoal with caustic and carbonated alkali : it is very porous, and is therefore easily penetrated. Instead of extracting it with water, the weak liquors from the decomposition of sodium oxalate with lime may be used. The lye thus obtained is causticised with lime and concentrated to 42° Bé. (sp. gr. 1·407), and is then again used in the process.

2. Thorn's Process.—Very little has been published on the subject of the most advantageous conditions for treating sawdust with alkalis for the production of oxalic acid; it appears therefore desirable to give the results of the experiments made by Thorn on this subject.

Thorn's earlier experiments were made in round iron pots 2 inches deep, 4 inches in diameter at the bottom and 5 inches diameter at the top; the whole quantity of sawdust taken was thrown into the boiling lye, which was of 30° to 42° Bé. strength, and the heating was continued over a free flame, with continued stirring. By using the more concentrated lye of 42° Bé. strength the whole was at once absorbed by the sawdust, and the inconvenient splashing of the liquid was prevented.

In the course of the experiments Thorn observed that variations in the yield resulted from heating the mixture in thicker or thinner layers; a second series of experiments was therefore made in shallow sheet-iron dishes, in which the mixture formed a layer only $\frac{2}{5}$ to $\frac{3}{5}$ inch thick. Pine-wood sawdust, containing 15 per cent. of hygroscopic moisture, was employed for the experiments. To estimate

the oxalic acid produced, 1 gram of the melt was treated with warm water, the solution being acidified with acetic acid, boiled to expel carbonic acid, and precipitated with calcium chloride; the washed precipitate was converted into calcium sulphate for weighing, and the amount of crystallised oxalic acid, $C_2H_2O_4 + 2H_2O$, per 100 parts of wood, was calculated.

1. *Formation of Oxalic Acid by Fusing Sawdust with Sodium Hydroxide alone.*—In one series of experiments 1 part of sawdust was added to a quantity of soda lye containing 2 parts of sodium hydroxide; in another series 4 parts of sodium hydroxide were taken. The following were the results obtained :—

50 grams of sawdust fused with 100 grams of NaHO in the iron pot yielded :—

At 200° C., 36·0 parts of oxalic acid per 100 parts of wood.
At 240° C., 33·2 „ „ „ „ „ „

When the mixture was heated in a thin layer :—

At 200° C., 34·68 parts of oxalic acid per 100 parts of wood.
At 220° C., 31·60 „ „ „ „ „ „

Using 25 grams of sawdust to 100 grams of NaHO :—
In the iron pot :—

At 240° C., 42·30 parts of oxalic acid per 100 parts of wood.

In thin layers :—

At 240° C., 52·14 parts of oxalic acid per 100 parts of wood.

The colour of the melt passed from brown to a bright turmeric yellow; above 180° the mass assumed a green or brownish-green colour; and at still higher temperatures a vapour with a disagreeable odour was evolved, indicating apparently that more extensive decomposition was taking place. Heating above 200° entailed great care to prevent the temperature from rising too high and causing the

redecomposition of the oxalic acid produced. This was especially the case with the smaller proportion of alkali.

2. *Formation of Oxalic Acid by Fusing Sawdust with a Mixture of Sodium Hydroxide and Potassium Hydroxide. in Thick Layers.*— Earlier experiments had shown that, by using a mixture of potassium hydroxide and sodium hydroxide in certain proportions, the yield of oxalic acid equalled, or even exceeded, that with potassium hydroxide alone.

The proportions which give the most favourable result have been very variously stated. According to a report by Fleck, a mixture of 1½ parts of potassium hydroxide to 1 part of sodium hydroxide was employed in an English works: according to another statement 1 equivalent of potassium hydroxide is taken to 1½ equivalents of sodium hydroxide: at Kunheim's factory in Berlin molecular proportions of KOH and NaOH are regarded as the most advantageous, which proportions agree approximately with those first stated above.

Starting with a mixture of 10 parts of potassium hydroxide, 90 parts of sodium hydroxide, and 50 parts of sawdust, Thorn observed that, with the alkalis in this ratio, the mass underwent a peculiar decomposition. Whether the mixture was heated up slowly or rapidly the colour of the mass passed from brownish-yellow to greenish-yellow, and when 180° was reached the mixture had the consistence of stiff dough. A dense smoke now rose from the melt: and in spite of the removal of the flame, the temperature increased, at first slowly, then rapidly, in the course of a few minutes, to above 360°. The mass intumesced, and formed craters from which issued large volumes of combustible gas: finally it became completely carbonised. The decomposition could not be arrested by blowing a strong current of cold air upon the mass. As often as Thorn repeated the experiment with these proportions he observed the same phenomena. When a mixture of 20 parts of KOH, 80 of NaOH, and 50 of sawdust was used,

the temperature could be raised to considerably above 200° without this uncontrollable decomposition ensuing.

As the proportion of potash is increased, the colour of the finished melt passes from yellow more and more into brown, and higher temperatures are required to produce the same consistence. Above 200° the mixture again becomes fluid, and froths so violently that it comes over the edge of the pot; with further heating it again becomes viscous. It is then difficult to raise its temperature, but if, after heating to 200°, it is cooled to 60° to 80°—stirring all the time to prevent the formation of lumps and to obtain a loose granular mass—it can easily be reheated to 240° to 250°. At this temperature the humus appears to undergo decomposition to some extent, as is evident from the paler colour of the solution, compared with that of a less strongly-heated melt. On the other hand, the formation of oxalic acid increases at this high temperature, as is shown by the following experiments, in which 50 grams of sawdust were fused with 100 grams of alkali containing different proportions of KOH and NaOH, each fusion lasting ¾ to 1 hour :—

Proportion of KOH : NaOH.	Temperature in degrees Cent.	Number of Experiments.	Percentage of Oxalic Acid.
20 : 80	190	2	19·78
20 : 80	200	1	21·50
20 : 80	240	2	30·04
30 : 70	190	3	21·38
30 : 70	240	4	38·89
40 : 60	190	1	14·00
40 : 60	200	3	30·35
40 : 60	240 to 245	4	43·70
50 : 50	200	2	25·76
50 : 50	240 to 245	4	39·04
60 : 40	200	3	30·57
60 : 40	240 to 245	4	42·67
80 : 20	200 to 220	4	45·59
80 : 20	240	3	61·32
90 : 10	240	2	64·24
100 : 0	240 to 245	3	65·51

Very different results were obtained when the mixture was heated in thin layers.

3. *Formation of Oxalic Acid by Heating Sawdust with a Mixture of Potassium Hydroxide and Sodium Hydroxide, in Thin Layers.*—As before, 50 grams of sawdust was thrown into boiling lye of 42° Bé., containing 100 grams of alkali hydroxide. The sawdust absorbed the whole of the liquid, and the mixture was then heated on an iron plate in a layer about $\frac{2}{5}$ inch thick. By vigorous stirring, the melting of the mass was, as far as possible, prevented, but above 200° a certain amount of fusion took place, and the mass acquired a pasty, granular consistence. When both alkalis were used this tendency to crumble increased, whilst the colour of the melt remained paler. The mass remained more porous than when heated in a thick layer, and was therefore better exposed to the action of the air. The increased contact with the air is advantageous, inasmuch as it assists the evaporation of the water, and promotes the oxidation of the woody fibre, which conduces to the formation of oxalic acid, as is shown by the following results. The heating lasted 1 to 1½ hours :—

Proportion of KOH : NaOH.	Temperature in degrees Cent.	Number of Experiments.	Percentage of Oxalic Acid.
0 : 100	200 to 220	2	33·14
10 : 90	230	2	58·36
20 : 80	240 to 250	4	74·76
30 : 70	240 to 250	3	76·77
40 : 60	240 to 250	6	80·57
60 : 40	240 to 250	6	80·08
80 : 20	245	4	81·24
100 : 0	240 to 250	6	81·23

This method of heating in thin layers, avoiding fusion as far as possible, gave therefore a considerably larger yield of oxalic acid. The experiments showed, further, that a mixture of 40 parts of KOH and 60 of NaOH, which

approximates to 1 equivalent of the former to 2 equivalents of the latter, gives practically the same yield as KOH alone. With smaller proportions of potash the yield rapidly falls off.

4. *Formation of Oxalic Acid by Heating Sawdust with Alkali Hydroxide, in Thin Layers in a Current of Heated Air.*—If a current of heated air is passed over the mixture during the heating up, the latter retains its pulverulent condition for some time, but first begins to soften at about 220°. The mass, which up to that temperature was of a uniform brown colour, began to show isolated black patches, which rapidly extended throughout the whole. The mixture was heated to 215° in air having a temperature of 100°; the temperature then rose spontaneously to 240°, whilst the mass became of a dark-brown colour. When a mixture of KOH and NaOH was used, the reaction did not take place so violently as with KOH alone, the mass remaining of a paler colour. When air heated to 120° was employed, the temperature rose rapidly from 190° to 250°, while the time required for heating up was materially shortened by the employment of heated air.

The experiments in which 50 grams of sawdust and 100 grams of KOH were taken gave the following results :—

Temperature of the Air.	Temperature to which the Mass was Heated.	Temperature acquired by the Mass after ceasing to apply Heat.	Number of Experiments.	Percentage of Oxalic Acid.
120°	220°	250°	2	78·27
100°	215°	240°	2	82·00
100°	220°	240°	2	82·60
100°	190°	240°	2	79·52
100°	190°	250°	2	80·64

The yield of oxalic acid was therefore no larger than in the experiments without heated air, but a shorter time of heating was required for the formation of the acid.

5. *Formation of Oxalic Acid with the Assistance of Manganese Dioxide.*—In 1858 Possoz took out an English patent, according to which the formation of ulmates, acetates, formates, and carbonates was avoided by heating 100 parts of bran, or other organic substance, with 100 parts of potassium hydroxide and 500 parts of potassium manganate, at 160° to 240° C., but not exceeding 260°.

Instead of potassium manganate, Thorn endeavoured to act on the heated mixture of sawdust and alkali hydroxide with manganese dioxide. The sawdust (50 grams) was heated with the alkali in a thin layer, and at 150° 100 grams of manganese dioxide was scattered over the surface. With 50 grams of wood, 100 grams of KOH and 100 grams of manganese dioxide, the average yield from four closely concordant experiments was 78·74 per cent. of oxalic acid: the addition of the manganese peroxide was therefore without any influence on the yield, and it did not appear that the dioxide underwent any change.

6. *Yield of Oxalic Acid from Different Kinds of Wood.*—To ascertain whether the kind of wood used would influence the yield of oxalic acid, several different kinds were tried. For each experiment 50 grams of wood were heated with 40 grams of KOH and 60 grams of NaOH at 240° to 250° C. in a thin layer, and the following average results were obtained in four fairly concordant experiments:—

	Percentage of Hygroscopic Moisture.	Percentage of Oxalic Acid.	Percentage of Oxalic Acid on Dry Wood.
White deal . . .	15·0	80·50	94·70
Yellow deal . . .	15·0	80·50	94·70
Poplar	14·0	80·10	93·14
Beech	8·6	79·00	86·43
Oak	6·5	75·12	84·42

The soft woods therefore give a larger yield than the hard woods.

7. *Yield of Oxalic Acid with Different Proportions of Wood and Alkali.*—If the quantity of wood is increased in proportion to the alkali, subsidiary decompositions of the wood take place, the wood undergoing dry distillation, and ultimately carbonisation. When 75 grams of wood were heated along with 100 grams of KOH, the mass began to fuse at 210°, and at 215° some black patches appeared in the pale-brown mass. The temperature rose slowly by itself to 250°, the mass turning quite black. With 100 grams of wood to 100 grams of KOH, the mixture became dark coloured even below 200°. In each of the following experiments 100 grams of KOH were employed, and the mass was heated to 250° :—

Quantity of Wood.	Yield of Oxalic Acid per 100 of Wood.	Yield of Oxalic Acid per 100 of KOH.	Mode of Heating.
Grams.			
50	65·50	32·75	Melted in thick layers.
60	54·56	32·73	
75	52·00	39·00	
80	47·12	37·70	
100	36·15	36·15	
50	81·00	40·50	Heated in thin layers.
60	76·30	45·78	
75	68·90	51·67	
80	66·77	53·41	
100	54·14	54·14	

In all the above cases the melting in thick layers gave a smaller yield than the corresponding mixture heated in thin layers. With the former of the two methods of heating, the proportion of 75 of wood to 100 of KOH appears the most favourable when the yield is calculated per unit quantity of the potash used : but with heating in a thin layer, the yield, calculated on the alkali, rises as the proportion of wood is increased. Considering the relatively low cost of the sawdust compared with that of the potash,

it would appear advisable to take such proportions as would give the largest yield for a given quantity of alkali; but there are practical difficulties in conducting the fusion and in the subsequent purification of the oxalic acid, which prohibit the use of much more than 50 parts of wood to 100 of alkali hydroxide.

The extraction of the oxalic acid from the melt can be performed in two different ways: the aqueous extract of the melt may be boiled straight away with milk of lime, to precipitate the oxalic acid as calcium oxalate, or, if both alkalis have been employed, the sodium oxalate may first be separated out by crystallisation.

Working by the former of the two methods a large quantity of calcium carbonate is precipitated with the calcium oxalate; this consumes an equivalent quantity of sulphuric acid, and therefore occasions a larger expenditure of both lime and acid than corresponds to the oxalic acid obtained. The size of the apparatus and the amount of fuel also have to be increased, because the amount of washing required, and therefore the quantity of liquid to be dealt with, increases as the quantity of precipitate augments.

Besides this, it is difficult to obtain pure oxalic acid from the precipitate prepared in this manner, because the humus substances which the solution contains are precipitated by the lime, adhere very obstinately to the precipitate, and on the subsequent decomposition with sulphuric acid yield a dark-coloured solution of oxalic acid. The whole of the alkali is recovered in the caustic state, but the liquor cannot be directly employed for another melting operation, on account of the large quantity of organic matter which it contains, but must first be evaporated, calcined, and again causticised, thus entailing a second consumption of lime. It is therefore far more advantageous to first crystallise out the sodium oxalate, the additional labour being fully compensated for by the

avoidance of the above disadvantages. The process of manufacturing oxalic acid from the melt may therefore be divided into the following five operations :—

1. Preparation of the solution.
2. Crystallisation of the sodium oxalate.
3. Conversion of the sodium oxalate into calcium oxalate
4. Decomposition of the calcium oxalate by sulphuric acid.
5. Crystallisation of the oxalic acid.

1. *Preparation of the Solution.*—The mass obtained by melting sawdust with the alkalis is boiled with water until nearly the whole of it is dissolved : the solution is then evaporated to 38° Bé.

2. *Crystallisation of the Sodium Oxalate.*—The solution becomes very slimy during concentration, in consequence of the presence of the humus; this introduces difficulties into the operation of separating the fine-grained crystals of the sodium salt from the mother liquor. If 4 parts of alkali are used with only 1 part of wood, practically the whole of the oxalic acid crystallises out (as sodium oxalate) from a solution concentrated to 38° Bé., and the mother liquor can be readily run off from the crystals, which are therefore left at once in a comparatively pure condition. If, however, only 2 parts of alkali are used with 1 part of wood, the mother liquor is very syrupy, so that it cannot be removed from the crystals by decantation or by ordinary filtration, and special arrangements for the separation become necessary. In the small-scale experiments a Bunsen filter-pump was used. By this the mother liquor was sucked out from the crystalline magma as completely as possible, and the crystals were then washed with small quantities of cold water until oxalic acid began to appear in the filtrate. In this way a fairly pure, pale-brown sodium oxalate was obtained. On the large scale, filter presses or centrifugal machines are used for separating the mother liquor from the crystals.

The sodium oxalate separates out in the form of a sandy powder which exhibits no definite crystalline forms. It forms rounded granules about the size of rape-seed; the larger granules being frequently hollow, while scales resembling the husks of hemp-seed are often observed at the edges of the crystalliser.

Another method consists in treating the melt with water at 16° C., by which the caustic and carbonated alkalis are dissolved, whilst the sodium oxalate remains undissolved. According to Thorn's experiments, however, although most of the sodium oxalate remains behind, a not inconsiderable amount of oxalic acid passes into solution, probably as potassium oxalate, which then must be precipitated with lime. If, on the contrary, the melt is dissolved completely by boiling, and the sodium oxalate allowed to crystallise, it is possible to obtain a mother liquor practically free from oxalate, because the potassium oxalate present in the melt is completely converted into sodium oxalate during the boiling.

3. *Conversion of the Sodium Oxalate into Calcium Oxalate.*—The sodium salt is dissolved in boiling water, a small excess of milk of lime is gradually added, and the mixture is boiled for about 2 hours. It is advisable to dilute the mixture well with water, since otherwise the decomposition is slow and a greater proportion of lime is necessary. If a filtered sample, acidified with acetic acid, still gives a precipitate with calcium chloride, more lime must be added. When the decomposition is complete, the caustic lye is drawn off, the precipitate being boiled several times with water and collected on a filter.

4. *Decomposition of the Calcium Oxalate by Sulphuric Acid.*—For this operation a large excess of sulphuric acid is always necessary, 3 equivalents being required for 1 equivalent of the oxalate. It is important in this operation to add an ample quantity of water to ensure the complete action of the acid. The calcium oxalate is

therefore stirred up with water to a thin paste, and the requisite quantity of sulphuric acid (15° to 20° Bé.) is added gradually, with stirring. The paste becomes at first somewhat stiff owing to the calcium sulphate (gypsum) formed, but after standing for a time it becomes thinner and can then be easily stirred, more water being added and the mixture gently heated for 1 to 2 hours with frequent stirring. Too high a temperature must be avoided, as the solution would then acquire a dark colour. When the decomposition is complete the liquid is filtered off and the precipitated gypsum washed: it must be well stirred up with the water, as it settles very rapidly.

The gypsum can either be used as manure, or be calcined and used as a plastering material.

5. *Crystallisation of the Oxalic Acid.*—The solution obtained contains, besides the oxalic and sulphuric acids, a small quantity of calcium sulphate. It is concentrated to 15° Bé. (sp. gr. 1·116), when on standing for 3 to 4 hours the calcium sulphate separates out in small asbestiform crystals. After removing these, the liquor is further concentrated to 30° Bé. (sp. gr. 1·261); the oxalic acid separates on cooling in long crystals, which are purified by several recrystallisations. The sulphuric acid is used in the next operation; if too much contaminated by organic matter it must be purified by concentration.

3. Bohlig's Process.—Potash lye, of 36° Bé., is heated to boiling in a stout iron pan, and common deal sawdust is added until a thick paste is obtained. The heating is continued with constant stirring, and when the water has evaporated, the mixture again becomes fluid, homogeneous, and of a turmeric yellow colour. The temperature is maintained at the same degree for 2 to 2½ hours, the fire being then drawn and the mass allowed to cool somewhat. Whilst it is still warm, enough water is added to give a solution of 40° Bé. strength: this is allowed to get cold after it has been well mixed by stirring. A very consider-

able yield of potassium oxalate, which is completely insoluble in potash lye of 40° Bé., is obtained. This method of preparing potassium oxalate is not new, although considerably improved : the subsequent treatment is, however, entirely new.

The well-washed and recrystallised potassium oxalate is dissolved in a large quantity of hot water, and the cooled solution is precipitated with magnesium chloride or sulphate (waste liquor from the manufacture of carbonic acid for soda water). The well-washed magnesium oxalate is heated in a wooden tub by a steam pipe, and concentrated hydrochloric acid is added until it is entirely dissolved. The clarified solution is run hot into stoneware pans; on cooling it yields oxalic acid in clean crystals, which after washing and a single recrystallisation are chemically pure. This rapid and economical process yields oxalic acid without any useless residues, so that it presents an evident advantage compared with previous methods.

4. Process of Roberts, Dale & Co.-- Messrs. Roberts, Dale & Co., at their soda works at Warrington, manufactured oxalic acid by gradually adding fine sawdust to a lye containing 1½ parts of caustic potash and 1 part of caustic soda, in iron pans. The mixture was then evaporated with constant stirring, so as to obtain a moist powdery residue. The caustic soda was thus converted into sparingly soluble sodium oxalate, and the caustic potash into potassium carbonate with small quantities of potassium oxalate. The mass has a brown colour due to the simultaneous formation of humus compounds. The material was thrown into iron filter boxes with wire-gauze false bottoms : water was run upon it and, by the action of a pump, connected with the space below the gauze, was drawn through the saline mass, dissolving the potassium salts in its passage. The washed residue, which consists of sodium oxalate, was decomposed by heating with milk of lime, in an iron pan with a horizontal stirrer, calcium oxalate and caustic soda

being formed. The soda lye was evaporated and used over again : the calcium oxalate, after it had been washed in the same manner as the sodium oxalate, was decomposed by sulphuric acid in wooden vats lined with lead. The solution of the potash salts separated from the sodium oxalate was likewise boiled with lime, to remove the oxalic acid and causticise the potassium carbonate, and the caustic potash lye obtained was used again as before. The solution of oxalic acid obtained from the decomposition of the calcium oxalate was evaporated to the crystallising point in lead pans, and the crystals obtained from the first and second evaporations were repeatedly recrystallised to eliminate the adhering sulphuric acid; the last mother liquor, diluted with water and mixed with a further quantity of sulphuric acid, being used for the decomposition of fresh quantities of calcium oxalate.

J. Dale has introduced an improvement on this process, which consists in treating the sawdust with a hot solution of soda or potash before fusing it with the caustic alkalis. This preliminary treatment removes most of the impurities from the wood-cellulose.

5. Preparation of Oxalic Acid from Lignose.—(*Chemically Prepared Wood.*)—The lignose obtained by treating wood with hydrochloric acid may also be used as the raw material for the manufacture of oxalic acid, the process being the same as that with sawdust. The action of sodium hydroxide on lignose produces a darker mass than when wood is used, the melts are more fluid and more closely resemble those in which a mixture of potash and soda has been used.

According to Bachet and Machard the treatment with hydrochloric acid dissolves the light spongy cellulose which forms the envelope of the incrusting substance, so that the proportion of lignin in the residue is increased, and the product, freed from the spongy cellulose, is more readily soluble in alkalis. Experiments, in each of which

100 grams of sodium hydroxide were employed, gave the following results :— (Horn for ref.

Lignose from 50 grams of Wood.	Temperature. Degrees Cent.	Number of Experiments.	Oxalic Acid per 100 parts of Lignose.	Oxalic Acid per 100 parts of Wood.	
32·7	190	2	23·67	15·39	Melted in thick layers.
25·8	190	3	20·79	10·37	
31·1	190	2	22·16	14·09	
31·4	190	1	26·40	16·58	
31·1	240	2	47·66	29·04	
31·4	205	3	31·03	22·58	Heated in thin layers.
31·4	240	2	49·36	31·00	

According to these experiments the yield of oxalic acid is about 33 to 38 per cent. smaller than when the original wood is melted with sodium hydroxide. This would seem to indicate that the spongy cellulose contributes more to the formation of oxalic acid than the residue left after treatment with hydrochloric acid, containing a larger proportion of lignin, and more readily soluble in alkalis.

6. Manufacture of Oxalic Acid by Zaiher's Process.—In this process the formation of humus substances, which are products of decomposition and oxidation, is avoided by conducting the fusion in a vacuum. The use of a vacuum permits the preliminary fusion to be performed at as low a temperature as 180°. It is advantageous to deprive the sawdust of water and air by heating it in the vacuum vessel before admitting the caustic lye, as this is then readily absorbed by the dry sawdust, the solution of the cellulose in the alkali taking place more readily. It is also possible to boil the sawdust in the apparatus with water or weak alkaline lye (4° to 6° Bé.), run out this liquor, exhaust the vessel, then draw in the strong lye and commence the fusion. The vessel used is a steam-jacketed boiler fitted with a stirrer, and with wide valves connected with a condenser or with an air pump,

adapted to be either heated by steam or cooled by water. After heating the boiler to 100° to 150°, the calculated quantity of sawdust, or other material containing cellulose, is thrown in, the stirrer is set in motion, and the air is pumped out, by which means the sawdust is freed from air and water. The concentrated alkaline lye, previously heated to a temperature not exceeding 130°, is then drawn in, the stirrer is kept in slow rotation, and whilst maintaining as perfect a vacuum as possible, the temperature is gradually raised to 180°. The preliminary fusion, or preparation of the melt, requires several hours, but when known raw materials are used it requires little attention. The mixture thus obtained is then reheated in the usual way with access of air, in shallow pans provided with suitable stirrers, yielding a dry, pulverulent, nearly colourless product.

260 parts of white deal or poplar sawdust, containing 20 per cent. of moisture, are placed in the boiler, and dried at 100° to 150° in an almost perfect vacuum, with the stirrer in motion, which takes about 30 minutes: 940 parts of hot (122°) potash lye (46° Bé.) containing 6 to 7 per cent. of potassium carbonate, previously concentrated in a separate vessel, are then admitted, and the preliminary fusion is performed whilst stirring slowly. This is complete in 3 hours. The mixture is then cooled to about 160° and, by reversing the motion of the stirrer, the pale-yellow fluid product is run out into a shallow pan, also provided with stirring apparatus. It is here slowly raised to 320°, stirring all the time, the operation requiring about 4 hours. The product is a light-grey powder, which readily dissolves to a nearly colourless solution in which no undissolved cellulose is present. By direct precipitation with lime it yields a nearly white calcium oxalate. The melt contains 32 per cent. of oxalic acid.

The best proportions are found to be $2\frac{1}{2}$ parts of caustic potash to 1 part of dry sawdust.

CHAPTER VI

MANUFACTURE OF SUGAR AND ALCOHOL FROM WOOD-WASTE

By the prolonged boiling of wood, especially if first reduced to fibres, with dilute mineral acids, part of the cellulose can be converted into sugar. If the saccharine liquid is suitably neutralised and then fermented, the sugar is converted into alcohol, which can then be distilled and rectified.

This process has the appearance of being a very simple and obvious method of manufacturing alcohol; nevertheless in practice a number of difficulties are encountered, so that, until recently, very little use has been made of this reaction.

Braconnot based his process for preparing alcohol from wood on the following facts: When dry cellulose, or wood in a finely divided condition, is mixed with concentrated sulphuric acid, heat being avoided, the wood is converted into a pulp. After several hours this is diluted with water and heated to boiling. After neutralising the acid with lime, the liquid can be fermented, and the fermented solution yields ordinary alcohol on distillation.

In Payen's experiments 500 grams of pine-wood, in pieces 1 centimetre thick, were boiled for ten hours with 2 litres of 10 per cent. hydrochloric acid, whereupon the liquid was found to contain 105 grams of dextrose, or 21 per cent. on the dry wood. It was then neutralised and fermented.

In the process given by Zetterlund, the sawdust was heated in a boiler with hydrochloric acid under a pressure

of 1½ lb. per square inch, the liquid being neutralised and fermented in the usual way. The materials used were :—

Very damp fir sawdust	990 lb.
Hydrochloric acid of specific gravity 1·18 .	77 „
Water	3410 „

After boiling for 8 hours the mass contained 3·33 per cent. of sugar, and after 11 hours 4·38 per cent. : no further increase could be effected. The whole mass now contained 195 lb. of grape-sugar, equal to 19·67 per cent. of the weight of sawdust employed. The acid in the mixture was then nearly neutralised with lime, leaving only an acidity equal to ½ degree on Lüdersdorff's acid scale. At a temperature of 30° the yeast from 22 lb. of malt was added. The fermentation was complete in 26 hours, and the wort yielded on distillation 5⅞ gallons of 50 per cent. alcohol, of agreeable flavour, and perfectly free from any odour, or taste, of turpentine. It may be assumed that the manufacture of brandy from sawdust on the large scale will become a success when experiments have settled the quantity of water to be added to the acid, and the length of time that the mixture should be boiled, these two factors having the greatest influence on the formation of the sugar. If it were possible to convert the whole of the cellulose of the sawdust into grape-sugar, 100 parts of air-dried sawdust would yield at least 24 parts of 50 per cent. alcohol. Sawdust from foliage trees would probably give the best results.

Bachet and Machard employ wood cut into discs, which they boil with dilute hydrochloric acid, and ferment the sugar solution so obtained, after neutralising it with calcium carbonate. The calcium chloride formed is inimical to the complete fermentation of the sugar. This difficulty may be met by substituting sulphuric acid for hydrochloric. The sawdust is boiled for 10 hours under high

pressure in a copper boiler with a liquid containing 1 to 1½ per cent. of concentrated sulphuric acid, the dark, amber-coloured liquid being neutralised with lime and submitted to fermentation with yeast.

The calcium sulphate produced by the neutralisation with lime opposes no obstacle to the complete fermentation of the sugar, but it would seem that substances which are antagonistic are formed by the action of the sulphuric acid on the wood.

The chief difficulties in the way of employing this process on the large scale are that—unless we assume a supply of sawdust to be available—very complicated machinery is required for comminuting the wood to the extent necessary for obtaining a sufficiently large yield of spirit (1 gallon from 1 cwt. of wood), and that in consequence of the bulkiness of the material very large vessels are necessary. It is also difficult to construct these vessels so that they will withstand the high pressure and corrosive action of the acid fluid.

Quite recently E. Simonsen has manufactured alcohol on the large scale at the Bache-Wiig works. A steam boiler, with a heating surface of 150·7 square feet, heated by a coal fire, and an autoclave with a capacity of 1650 gallons, lined with lead, were employed. The autoclave was a cylinder, which could be rotated, and was furnished with two manholes, steam pipe, testing and drawing-off taps, and a thermometer. The pressing was effected with an ordinary hydraulic press. For the neutralisation, and subsequent fermentation, wooden tubs, of 660 and 880 gallons capacity respectively, were employed. Two other neutralising tubs, and six auxiliary tubs of 143 and 154 gallons capacity, were required.

The routine of the work was as follows :—

1. The autoclave was charged with 220 lb. of sawdust and 660 to 1100 lb. of sulphuric acid (0·5 per cent. strength).

2. Steam was admitted until the temperature reached 100° C.; part of the air was blown off and the taps were all closed.

3. The mixture was heated to 174° C. (135 lb. pressure per square inch), and kept at that temperature for half an hour; the steam was blown off, the autoclave emptied, and the undissolved sawdust pressed.

4. The saccharine solution was neutralised with lime, leaving it, however, feebly acid, and then, at 25° C., was separated from the sediment of gypsum.

5. The necessary yeast, with a small quantity of nutrient material, was added, and the whole was allowed to ferment.

6. At 25° C. the fermentation was generally complete in 3 to 5 days, though occasionally it required longer. Its progress was watched by methodical estimations of the decrease in the percentage of sugar present.

7. Finally, the alcohol was distilled off, a single distillation giving a 15 per cent. spirit, a second distillation gave alcohol of 75 per cent. strength.

The results obtained may be summarised as follows:—

1. It does not appear to be of any moment whether the sawdust is fine or coarse; regard must be paid to the amount of moisture which it contains, the amount of water and sulphuric acid being regulated accordingly.

2. Pine- and fir-wood yield approximately the same amount of alcohol, but birch sawdust gives a larger yield of sugar.

3. Wood-shavings are quite as good for the purpose as sawdust, but they must be cut up small, across the grain.

4. The amount of liquid must be in the proportion of 4 parts to 1 part of sawdust.

5. The acid must amount to exactly 1·5 per cent. of the total liquid.

6. The pressed residue may be used as fuel.

7. The quantity of sugar solution obtained varies with

the amount of condensed steam and the temperature of the liquid run into the autoclave.

8. The proportion of sugar in the liquid generally approximates to 5 per cent.

9. The total sugar produced amounts to about 22 parts per 100 of dry sawdust; in a small-scale experiment, however, birch sawdust gave a yield of 30·8 per cent.

10. The fermented liquor contains 1·1 to 1·7 per cent. of alcohol; in the most successful operations $\frac{3}{4}$ gallon of absolute alcohol were obtained from 1 cwt. of sawdust containing 20 per cent. of moisture.

11. The quality of the alcohol is most satisfactory

That cellulosic materials, such as waste wood, sawdust, etc., could be converted into sugars by the action of dilute acids had therefore been known for a good many years, but the yield was so small that it did not seem possible to develop the process into a remunerative commercial operation. During recent years, however, much more successful results have been obtained, and not only are soluble carbohydrates so formed, but by their fermentation large quantities of ethyl alcohol are being regularly produced.

In 1900 Classen took out two patents for the conversion of wood into sugars, the first patent (Eng. Pat. 258, 1900) claims that by heating cellulose or wood in a closed vessel, at a temperature of 120° to 145° C., with a solution of sulphurous and sulphuric acids (*i. e.* 2 per cent. of SO_2, and 0·2 per cent. of H_2SO_4), or with a mixture of sulphurous and hydrochloric acids, sugars are formed, and that by using the same liquid for treating a fresh batch of material it was possible to obtain a liquid containing 10 per cent. of sugars, 80 to 90 per cent. of which were fermentable, the time for each operation being about 15 minutes. In the second patent of the same year (Eng. Pat. 259, 1900) he proposes to take 1 part by weight of air-dried sawdust, which will contain perhaps 15 per cent.

of moisture, and ¾ part of dilute sulphuric acid (chamber acid), which are mixed together, resulting in the formation of a greenish product, which, however, is quite dry and contains no sugar. On submitting this mixture to considerable pressure in a hydraulic press, heat is generated, and a chemical action sets in, which results in the formation of a hard, black mass, from which sugars can be extracted by treatment with water, and which, after neutralising the acid with carbonate of lime, can be fermented to form ethyl alcohol in the usual manner. According to Classen the proportion of sugars formed by this method is 40 per cent., which can be increased to 60 per cent. by using stronger acid, but is lowered by employing an acid of weaker strength. In one of the patents of 1901 (Eng. Pat. 4,199, 1901) he claims the use of sulphur trioxide vapours, either alone or in conjunction with sulphurous acid, at 100° C.; or after treatment with the vapours the material is heated in closed vessels at 125° C. In a later patent of the same year (Eng. Pat. 12,588, 1901) sulphurous acid is again resorted to, the proportions being 100 parts of wood containing 25 to 30 per cent. of water, and 30 to 35 parts of an aqueous solution of sulphurous acid, the operation being performed in a closed vessel at a temperature of 120° to 145° C., with agitation for 30 to 60 minutes. Oxidising agents may, in addition, be employed, but these are not altogether necessary, since a certain proportion of sulphuric acid is formed in the reaction. A mixture of sulphurous and sulphuric acids may be employed as an alternative method. In a later patent (U.S. Pat. 695,795, 1902) it is proposed to employ either chlorine or a chlorine-producing substance at a temperature of 120° to 145°, and then to add compounds of sulphur, which will, in reaction with the chlorine, give rise to the formation of sulphuric acid.

In the French patent (Fr. Pat. 448,496, 1912) Classen

introduces as a modification of the process of heating with sulphurous acid under pressure, in which sulphuric acid is formed by oxidation, the employment of catalysts such as finely-divided platinum or other metal or ferric oxide, and he states that with the use of these agents the proportion of sulphurous acid necessary for the hydrolysis is much reduced. For instance, 100 kilos of wood containing 15 to 50 per cent. of moisture are heated with 15 to 20 kilos of a saturated solution of sulphurous acid, and a proportion of the catalyst for 30 to 60 minutes in a closed vessel at 110° to 135° C.

Two other patents on the same lines may be mentioned. F. E. Gallagher (U.S. Pat. 1,056,161, 1913) proposes in his patent to digest the ligno-cellulose or other cellulosic raw material with steam under pressure, together with a hydrolysing agent, until the maximum amount of material has been rendered soluble; the mass is then digested at a lower temperature for an extended period with the object of converting as much as possible into fermentable sugars. F. E. Gallagher, Newton, and H. S. Mack (U.S. Pats. 1,056,162 and 1,056,163, 1913) claim also the employment of sulphite liquor, containing fermentable sugars obtained by a previous treatment of a batch of wood, and also the chlorination of ligno-cellulose and subsequent steaming of the product in presence of sulphuric acid for the generation of sugars.

The object of most of these processes is not primarily for the production of sugar, but with a view to the conversion of the cellulosic material into alcohol. The sugars formed can, however, be used directly as cattle foods after suitable treatment. J. Kōnig (Ger. Pat. 265,483, 1912) treats the wood (preferably of conifers) with dilute alkalies (*e. g.* ammonia), followed by a dilute acid, either with or without pressure, according to circumstance, or reverses the action, using first acid and then alkali, the proportions of the two being exact equivalents, so that a neutral

product is formed. The liquors are then evaporated together, or they may be evaporated separately and afterwards mixed, and other products suitable for use as cattle food may be incorporated.

A. Zimmermann [1] describes a product which he terms "Sacchulose," formed by heating sawdust with a solution of sulphurous acid at a pressure of 90 to 100 lb. This is a light, friable material, which contains about 25 per cent. of sugars, but owing to its porous nature, in contact with air it rapidly becomes oxidised and soon deteriorates. To overcome this difficulty it is mixed with a proportion of molasses, and the product passes under the name of "Sacchulose." According to the author the cellulose in the product has been so far modified that it is capable of easy digestion. The product of the action of sulphurous acid on sawdust was first prepared with a view to its ultimate conversion into alcohol, but the restrictions imposed by the Spirit Act of 1880 made this quite impossible, therefore the alternative of employing the material as a cattle food was decided upon rather than the total abandonment of the enterprise. Of the sugars prepared in this way 80 per cent. were found to be fermentable, and it was possible to produce from 1 ton of wood 30 to 35 proof gallons of spirit. The above-named authority states that in a factory treating 200 tons of sawdust per week it would be possible to manufacture 300,000 to 400,000 proof gallons of spirit per annum, and, in addition, as by-products 2000 gallons of methyl alcohol, 50 tons of acetic acid and 10 tons of furfural.

In a very comprehensive paper by Prof. R. F. Ruttan, M.D.,[2] it is stated that many attempts have been made to manufacture sugar and alcohol from wood. That sugar could be produced by the action of acids on wood cellulose was first demonstrated by Braconnet in 1819 Subse-

[1] *Jour. Roy. Soc. Arts.*, 1912, 69.
[2] Prof. R. F. Ruttan, M.D., *Jour. Soc. Chem. Indt.*, 1909, 1290.

quently several patents have been taken out embodying this reaction, for instance, that of Einar Simonsen in 1898, for the production of sugar or glucose from sawdust by heating it with dilute sulphuric acid, and later by Classen and others, in which processes sulphurous acid is employed. The use of the latter in the manufacture of wood pulp is, however, quite common, and has been so for a good many years. It was also known that in the reaction sulphuric acid was formed, and in order to prevent the undue decomposition which its presence gives rise to, calcium sulphite was employed to neutralise it.

Wood-waste and sawdust are in many localities of no value whatever; in a few places they may be of use locally as fuel for boiler purposes, and some works burn all that they produce. In a few cases it can be sold at a profit, but as a rule it has to be disposed of to sawdust burners, at a cost of 20 cents per ton, or is piled up on waste land or dumped into the nearest stream; in any case being more or less of a nuisance. Near any mill where sawdust or waste wood is produced it is reasonably certain that large quantities of it could be obtained if it was carted away; the cost for handling and transportation under ordinary conditions amounting to probably not more than 30 to 50 cents per ton.

The cost of the raw material being so very favourable, it is not surprising that many attempts have been made to utilise sawdust in the manufacture of alcohol, but none of these attempts was at all successful until Dr. Andrew Classen, of the Polytechnic School at Aachen, in 1900, demonstrated that sugars were formed when wood is heated with an aqueous solution of sulphurous acid under pressure, and that these sugars could be fermented by yeast in the ordinary manner with the production of ethyl alcohol. Classen took out several patents, which are mentioned above, but the methods described in the first patents were found unworkable. After several experi-

ments in a small plant erected at Aachen much more satisfactory results were obtained, and this led to the method being tried on a larger scale in America at a plant erected at Highland Park near Chicago. The results here were so promising that a still larger plant was installed at Hattiesberg, Miss., the plant consisting of apparatus for the generation of sulphurous acid; a revolving cylinder, 30 ft. long, and about 36 in. diameter, jacketted and constructed of iron and lined with sheet lead for use as a digester or converter; a series of tanks in which the treated sawdust was subjected to the action of hot water for removal of the sugar; neutralising vats in which the liquid was neutralised with calcium carbonate. In addition there were fermenting vats and stills for separating the alcohol as in an ordinary distillery.

The operation was commenced by charging the wood-waste into the converter until it was practically full, then about one-third of its weight of a saturated solution of sulphurous acid was pumped in, the converter closed, and steam under pressure admitted to the jacket while the cylinder was revolved. In from 4 to 6 hours the conversion was completed; the steam and sulphurous acid were then blown off into absorption tanks in which the excess of the latter was condensed and thus recovered. The cover of the apparatus was then removed, and the sawdust, resembling finely-ground coffee, was turned out. The treated material was extracted with hot water in the battery of tanks on the counter-current system, in which the whole of the sugars were extracted. The yield of sugars was stated to be 350 to 400 lb. per ton of wood treated, and after neutralising and fermenting with yeast 18 to 20 gallons of absolute alcohol were obtained. The residue, amounting to about 65 per cent. on the dry material, was burnt. Although it is assumed that the cellulose is attacked and converted into sugars, this does not appear to be the case, since the amount dissolved in

all cases approximates to the proportion of non-cellulosic ingredients or lignone, and the residue represents the cellulose.

Unfortunately this process was not a commercial success, the time required for the conversion being much too long; besides which the lead lining of the converter, after two or three charges had been operated, required renewal or repair, which not only added to the expense, but was a source of great trouble. The plant, which had cost £250,000 to construct and run for a year, had therefore been left idle for some considerable time. Two chemical engineers, Malcolm F. Ewen and G. H. Tomlinson, who had been associated with the Classen process, both in Germany and the United States, continued the investigations, and eventually evolved a process which, while having none of the drawbacks of the original method, had certain advantages, and this process is now operated successfully on a very large scale. The process was first tried on a factory scale in 1909 at Chicago Heights, near the city of Chicago, in a plant erected by the Wood-Waste Products Co., now the Standard Alcohol Co. of America, which has the control of the Ewen-Tomlinson patents. The converter used in this process is a revolving cylinder 12 ft. long and 8 ft. diameter, constructed of steel and lined with fire-bricks laid in a cement of glycerine and lead oxide. The wood is charged in through an opening, which is then closed, and the requisite quantity of sulphurous acid gas, about 1 per cent. on the weight of the wood, is introduced by means of a perforated pipe passing through the trunnions. Live steam is also passed in through the same pipe until a pressure of 100 lb. is attained, which occupies about 15 minutes. The cylinder is slowly revolved for another 40 to 45 minutes, whereupon the operation is complete. The extraction of the sugars and the fermentation are conducted as in the older process.

Dr. Ruttan gives particulars of two tests which he

himself made with this plant, the results being placed together below :—

	1	2	
Weight of wood taken	3623 lb.	2992 2105	shavings. hardwood sawdust.
Moisture, per cent.	18·61	—	
Dry wood basis.	2948·8	3058	

The products obtained from the converter had the following composition :—

	per cent.	per cent.
Moisture	32·23	34·63
Total reducing sugars	13·70	14·28
Calculated to dry basis	20·20	24·18
Total acidity as sulphuric acid	1·23	1·12
Sulphuric acid (SO_3)	0·418	0·352
Reducing sugars fermented	10·70	10·97
Unfermentable sugars (xylose, etc.)	3·00	3·21

These two charges were extracted together with water, the total liquid amounting to 2984 gallons, or 26,150 lb., containing 5·6 per cent. of sugars calculated as glucose. The liquid was neutralised, fermented and distilled, yielding 115·92 gallons of proof spirit, corresponding to 61·66 gallons of 94 per cent. alcohol. Estimates of cost are given, which show that without taking into account the Government tax, alcohol from wood-waste could be sold at 20 to 25 cents per gallon, whereas that from grain costs 52 cents. It is, however, claimed by the Standard Alcohol Co. that they could, with a larger plant, produce alcohol at as low as 7 cents per gallon.

A much larger plant than the one above mentioned was in course of construction for the Du Pont Powder Co., at Georgetown, S.C., at the time this communication was made (1919), and since then others have been built. One of these, mentioned by G. H. Tomlinson,[1] built for the

[1] G. H. Tomlinson, *Chem. & Met. Eng.*, 1918, 552. See also R. von Demuth, *Z. Angem. Chem.*, 1913, 786.

Standard Alcohol Co., is at Fullerton, La., and cost $456,920, the converter and extractor plant costing $200,000.

In 1913 a test was made with this plant extending over 22 days at $\frac{3}{4}$ capacity, when 6125 tons of green waste wood were treated, the moisture in which amounted to 48 per cent. The sugar solutions totalled in the aggregate 1,688,000 gallons, containing about 10·3 per cent. of sugars. The total cost of this solution, after allowing for depreciation, etc., amounted to 31·8 cents per 100 gallons. When this is concentrated to 12½ gallons its cost amounts to 3 cents per gallon, and it would yield 0·39 gallons of proof spirit. On the other hand, the same amount of cane molasses yields about 1 gallon of proof spirit. In practice it was found that although 24 per cent. of the wood calculated on the dry material was rendered soluble, only about 8·5 per cent. was in the form of fermentable sugars. The author is, however, of the opinion that by rigid chemical control a product fully equal in value to cane molasses could be produced.

F. W. Kressmann [1] has made some experimental determinations of the amount of sugars produced by the action of sulphuric acid upon white spruce and western larch sawdust. The apparatus consisted of a digester of thin cast iron, 5 ft. long and 2½ ft. diameter, lined with an acid-proof enamel. The charge consisted of 100 lb. of sawdust and 2 lb. of sulphuric acid diluted so that at the end of the steaming the total liquid amounted to four times the weight of the sawdust. The best results were obtained by heating with steam under a pressure of 7½ atmospheres. With spruce the yield of sugars amounted to 22 to 23 per cent. on the weight of the dry wood, of which about 70 per cent. was fermentable. About 1·4 per cent. of acetic acid and 0·1 to 0·6 per cent. of formic acid were also produced. The yield of alcohol on the dry wood amounted to 8·54 per cent. With western larch 29·7 per

[1] F. W. Kressmann, *Jour. Ind. Eng. Chem.*, 1914, 625; 1915, 920.

cent. of sugars were formed, 37·9 per cent. of which were fermentable, and the yield of alcohol was 4·98 per cent. on the weight of the dry wood.

Methyl or Wood Alcohol : CH_3HO. The aqueous liquid obtained in the distillation of wood contains acetic acid, methyl alcohol (about 4 per cent.), acetone, allyl alcohol, phenols, etc. It is separated, neutralised with lime and then distilled, yielding a crude methyl alcohol, while acetate of lime remains in solution and is recovered by evaporation. This commercial methyl alcohol, known as wood spirit, wood naphtha, and pyroxylic spirit, has a specific gravity of 0·796 to 0·875, and contains varying quantities of methyl alcohol. The crude material contains 35 to 40 per cent., and ordinary commercial spirit from 75 to 95 per cent. of the alcohol. After rectification the alcohol is sold in the United States under the names of " Columbian Spirit " and " Manhattan Spirits," in Canada as " Green Wood Spirits " and " Standard Wood Spirits," and in Germany as " Pro Spirit." Crude wood spirit contains varying proportions of methyl alcohol, acetone, methyl acetate and formate, dimethylacetal, allyl alcohol, aldehyde, methylamine, oil, water, etc. The " tailings " contain furfural, methyl-ethyl ketone, and allyl acetate with small quantities of paraxanthine.[1]

Several attempts have been made to utilise the organic material in the soda and sulphite lyes from wood pulp manufacture. For instance, A. H. White (U.S. Pat. 1,197,983, 1916) proposes to rapidly distil it by feeding it slowly into a retort heated to about 230° to 370° C., when it foams considerably and is quickly charred, yielding methyl and other compounds which are collected and utilised. The use of a catalyst in this reaction is also mentioned.

[1] C. Baskerville, *Jour. Ind. Eng. Chem.*, 1913, 768.

CHAPTER VII

PATENT DYE-STUFFS (ORGANIC SULPHIDES, SULPHO-DYES OR MERCAPTO-DYES)

By a process which has not become very generally known, Croissant and Bretonnière prepare from sawdust, decayed wood, horn, bran, starch, gluten, etc., dye-stuffs which they call organic sulphides because they contain sulphur replacing hydrogen. For example, to convert bran into a dye, it is placed in an iron pan which has a flanged edge; certain proportions of caustic soda and flowers of sulphur are added, the whole is worked into a uniform mixture, the pan being closed with a cover, and heated to 250° to 300° C. The sodium sulphide which is formed acts on the organic matter, removing hydrogen, which escapes as hydrogen sulphide, and adding sulphur. When the operation is complete, the pan contains a black, friable, hygroscopic mass, which dissolves completely in water. The solution, which is of a fine sap-green colour, smells of garlic or mercaptan and has a remarkable affinity for organic fibre, which it dyes without the use of a mordant. One and the same organic substance dyes several shades according to the proportions and the temperature employed. Certain substances, such as dye-wood extracts, aloes, etc., yield dyes even at the temperature of boiling water; others, such as wood-fibre, bran, etc., require a higher temperature. We give here two examples :—

1.

Aloes	6 lb.
Caustic soda solution of 40° Bé.	2 gallons.
Water	2 ,,
Flowers of sulphur	6 lb.

By operating at boiling temperature a greyish-lilac is obtained; at a higher temperature a dark brown.

2.

Humus (or rotten sawdust) . . .	45 lb.
Normal sulphide	9 gallons.

The normal sulphide is made from 17 gallons of 40° Bé. soda lye of 14½ gallons of water and 44 lb. of sulphur. By the combination of sulphur with various organic substances an almost unlimited series of entirely new dyestuffs has been obtained. In some cases the sulphur appears to enter into direct combination with the organic substance, without displacing any of its constituents, in which case the reaction takes place at a moderately low temperature, such as 100° to 120° C. This is the case with aloes. In by far the greater number of cases, however, the sulphur combines with the hydrogen of the organic substance, hydrogen sulphide being then evolved and the hydrogen replaced by a molecular equivalent of sulphur. For this reaction, temperatures of 250°, 300° and even higher are necessary. In both cases, however, the substance acquires dyeing properties which it did not previously possess. One and the same material will yield various shades according to the temperature, the duration of the heating, and the proportion of sulphur compound employed. In general the dye obtained approaches black, or at least brown, is the more soluble in water, and gives the faster dyes the higher the temperature and the greater the length of the heating. The dye obtained from decayed oak is extremely soluble in water; its odour resembles that of garlic or petroleum, and it has great affinity for fabrics. The dye from wheat-bran may be regarded as typical of a series. It differs somewhat in the mode of its preparation from that made from humus, for which previously prepared sulphide is used, the bran being mixed with flowers of sulphur and caustic soda. When

this mixture is heated, sodium sulphide is formed, so that the same conditions are produced as in the former case; but as this method allows the proportions of sulphur and soda to be varied, and the resulting shade to be thereby modified, it is preferable to the other.

The dye obtained from wheat-bran is easily and completely soluble in water, has a garlic odour, and has great affinity for fibres, as well as an extraordinary dyeing power. The dyed fabrics are greenish when taken out of the dye-bath, but after immersing in a solution of bichromate of potash acquire a catechu-brown shade, which inclines to grey after treatment with boiling soda. This change is characteristic of the products from bran, etc., and generally of all nitrogenous substances. The tendency to be changed to grey by soda solution is also influenced by the amount of sulphide employed; the larger the quantity of sulphide, the greener is the solution of the dye, and the more marked the change to grey produced by soda.

The dyes obtained from sawdust give particularly fast shades. The best woods for the purpose are oak, beech, cherry, chestnut, etc., whilst the soft resinous woods are unsuitable. The sawdust must be dry, and finely sifted. It may be converted into humus by piling it in heaps which are watered from time to time, and then gives results almost identical with those of old decayed wood.

Sawdust, which has been moistened with urine for several months with the object of rendering it nitrogenous, yields dyes which behave similarly to those from bran and other nitrogenous substances. The dye from sawdust is almost inodorous, dissolving in water with a brownish-black colour. The dye is taken up readily by the fibre which it dyes a dark greenish-grey, not altered by bichromate or by soda. The shade is fast to light, acids, air, alkalis, and soap.

These dye-stuffs are very hygroscopic; they must be protected from damp by keeping them in well-closed tins.

If this is not done they gradually decompose, absorbing oxygen and becoming insoluble and therefore unfit for use. The same is the case if the dye-bath is prepared too long before it is wanted for use. In a lukewarm bath the dyes have a great affinity for fibres, giving fast shades without the use of any mordant. The older the dye-bath the smaller is the affinity of the dye for fabrics; after 4 to 5 months it is destroyed completely. The baths should therefore only be made up in sufficient quantity for immediate use. The quality of the water used for the baths is far from immaterial, calcareous waters being quite unfit for use, since they immediately produce an almost insoluble, flocculent precipitate. The advantages of these patent dyes may be stated as follows: (1) Their manufacture is extremely simple, requiring neither expensive appliances nor complicated apparatus, and but little labour; moreover, the result of the manufacturing operations is perfectly certain. (2) The tinctorial power of these products is considerably greater than that of most other dyes. (3) The dyes are very fast, at the same time they resist both acids and alkalis better than any hitherto employed. (4) They are cheaper than the commonest dyes, especially when their remarkable strength is taken into account. For example, a pound of dye from sawdust costs little more than half as much as logwood extract, but will dye four times as much fabric. The new process is therefore capable of converting into dyes, by a simple method and at a low cost, materials which are everywhere accessible and possess little value; it is moreover capable of producing directly from these materials an unlimited series of completely new dye-stuffs of very divergent shades.

CHAPTER VIII

ARTIFICIAL WOOD AND PLASTIC MATERIALS FROM SAWDUST

PRODUCTION OF ARTIFICIAL WOOD COMPOSITIONS FOR MOULDED DECORATIONS.—The use of sawdust for the production of plastic compositions, which may be shaped either by pouring or by pressing into moulds, has been known for a considerable time, and the methods for the preparation of these compositions have been so much improved that articles which leave nothing to be desired are now produced by this means. Attempts have been made to manufacture planks, boards, beams, etc., from sawdust, but these endeavours have never met with success, because the lacerated wood-fibres, even when reunited by the most suitable binding materials, no longer possess the elasticity and strength of the natural wood. It is not to be expected that sawdust can ever be made to produce a material equal in all respects to the original wood, and we shall therefore confine our attention to those products which possess a practical value.

The idea of replacing wood by artificial products seems to have originated in China and Japan. Thence the invention reached Europe during the eighteenth century, and was especially applied in England, where, in 1772, Clay took out a patent for the preparation of such materials. Numerous processes for the production of artificial wood have been published, some of which differ widely from one another. The oldest methods are those in which finely disintegrated vegetable fibres, paper pulp, lime and rice

starch are mixed. Later Jennens introduced improvements, and is said to have had a factory at Birmingham where artificial wood articles were manufactured in great variety. The basis of these was chiefly a kind of paper pulp, which, by the addition of glue solution, chalk, clay, and linseed oil, was made into a dough which could be kneaded and shaped, and which acquired great hardness and durability when dried. The product was employed for the ornamentation of ceilings, mirrors, picture frames, etc. A similar material, which could be poured in the liquid state into moulds, was composed of sawdust or other finely subdivided vegetable fibre, refuse hair, and hemp, with glue solution, white of egg, caoutchouc, pitch and turpentine. The "*Simili bois*," made in Paris, and used with good effect for imitation wood-carvings, is a preparation of the same character. According to a proposal of Brindly, who obtained a patent for its use in manufacturing lacquered wares, tea-caddies, etc., a mixture was made of paper pulp, paper waste, hard soap, and alum.

The general method of preparing these compositions is to mix sawdust with a binding material, and then, according to consistence, either pour or press the mixture into moulds. The articles so prepared may be used for all kinds of decorative work, instead of the more costly wood-carving, especially for frames, small boxes, and various fancy articles. Artificial wood is also employed in making brushes; the bristles are inserted into a slab of the soft composition, which is then covered with a plate, perforated to let the bunches of bristle pass through. The application of pressure binds both into a single mass, and the brushes so made are both cheaper and more durable than those made by the methods most commonly in use.

The first artificial wood of this kind consisted of a mixture of sawdust, glue, and certain tanning solutions, or of sawdust, turpentine, resin, etc. Latry, in Paris, prepared artificial wood from sawdust and blood albumin by

the application of heat and pressure. Very fine sawdust, especially that of poplar-wood, is soaked in diluted blood, and dried at 50° to 60° C. The mixture is submitted to high pressure in steel moulds, which at the same time are heated to 170° to 200° by gas flames. At this temperature the blood undergoes an incipient liquefaction, and the whole becomes a blackish liquid resembling asphalt. The product is a hard material of woody texture, which can be sawn, glued, polished, lacquered, and gilded, exactly like wood. Articles made of this material were sold as "*Sciffarin ware.*" According to another formula, wood-fibre prepared as for paper-making was saturated with glue solution, pressed, and dried. This furnished a hard material, which was then protected from the action of moisture by several coats of thick linseed-oil varnish applied hot.

Another composition, bearing a resemblance to these artificial woods, is the so-called *wood marble*, which is made from the sawdust of fine, hard woods, ivory waste and other waste materials, to which pigments are often added. These, by the addition of water-glass, glue, etc., are made up into a hard mass, from which veneers are then cut, which, naturally, are not liable to warp or crack The material takes an excellent polish, which gives it the appearance of the finest marble.

A composition consisting of $\frac{1}{3}$ of sawdust, $\frac{1}{3}$ of calcium phosphate, and $\frac{1}{3}$ of a gelatinous or resinous material, goes by the name of "*Simili bois*," and is used for the reproduction of sculpture.

Quite recently articles of this character have been made from sawdust compositions, for the decoration of all kinds of woodwork, such as door lintels, brackets, capitals of pillars, cornices of cabinets, panels of chests, decorative mouldings, etc.; and it is well known in the furniture trade that ornamental articles of every kind, and imitation wood-carvings such as are used for furniture, fancy work

toys, as well as for house decoration, are most extensively prepared by moulding. But whilst these manufactures are largely employed in France, England, and America, they appear as yet to have obtained little footing in Germany and Austria. It is difficult to understand why, in spite of the great progress in cabinet work, very little wood-carving is employed in furniture.

These products have been so perfected that for cheap furniture, wall and ceiling decoration, etc., they are capable of completely replacing wood-carving, and such decorations in semi-relief have specially gained acceptance as substitutes for wood-carvings. Articles of artificial wood must fulfil the following requirements :—

1. They must resemble wood as closely in appearance as possible, and have approximately the same specific gravity.

2. They ought not to warp with heat or damp, and must be sufficiently tough, as well as hard, to prevent the edges from breaking off too readily.

3. They must permit of being bored, filed, sawn, cut and carved, without being brittle : they cannot, of course, be split, since their structure is perfectly uniform.

4. They must admit of being glued, without special difficulty, to the objects to be decorated, and must adhere well.

In Germany, B. Harrass of Böhlen (Thuringia) has for several years been engaged in the preparation of artificial wood; and the material which he produces fully deserves that name, since his manufactures exhibit the choicest forms in the various styles, and a great diversity in the individual articles, which are supplied by him as complete ornamental fittings both for furniture and house decoration. The panels and friezes of the Italian Renaissance are altogether unlike the unsightly forms which are still exhibited by the wood-carvings of the German Renaissance. The ornamental objects supplied by Harrass have

an artistic character of their own, whilst they are free from the objection to wood-carving on account of its costliness.

Not furniture alone, but the walls and ceilings of our dwellings may by the use of artificial wood, at a cost which scarcely exceeds that of stucco, be decorated with panelling of high architectural quality. As in the dwelling-houses of the present day the skirting-boards and base mouldings form the only relics of the heavy panelling of our predecessors, the patented invention of Harrass supplies the demand which is arising on all sides for the restoration to favour of wood architecture for chamber decoration, inasmuch as the use of artificial wood furnishes every builder with the means of producing, at a low cost, wainscoting equal to the few examples which have come down to us from the best days of the Florentine School.

The manufacture is, however, in no sense an imitation, nor, as the name would seem to imply, a substitute for wood, but in its outward layer consists of natural woods (walnut, oak, mahogany, or rosewood), which Harrass makes plastic by giving them a basis of wood-fibre bound together by albumin into a homogeneous, insoluble mass. The artistic objects produced in this way are far more durable than those made by carving natural wood, are far cheaper, and at the same time better finished than most carvings. To their employment for artistic furniture and house decoration may be added their use for a great variety of other objects, such as photograph frames, mirror frames, etc., all of which are turned out in an equally finished style.

In the above account the author has endeavoured to give a general idea of the amplitude of the field which is open for utilising sawdust in the production of artificial wood. Many have been the attempts made to replace wood-carvings by other and cheaper forms of ornament, such as papier-mâché, and even cast-zinc, but these, partly on

account of the difficulty of affixing them, partly in consequence of their want of artistic finish, but mainly because they did not resemble wood in appearance, have never met with success. An obvious expedient, therefore, appeared to be the use of wood itself for such objects; and already a large number of processes are known, which in recent years have effected marked advances in this direction by means of the employment of wood-cellulose.

The Preparation of Artificial Wood for Moulded Decoration.—As already mentioned, all artificial wood-compositions consist of sawdust, or spent dye-woods, and a binding material, which may be of various kinds. The binding material is either soluble in water and remains soluble, or is rendered insoluble by special treatment, or else is insoluble. According to the nature of the binding material, the mixture is either of the consistence of dough, so that it can be pressed into moulds by hand, or it may be fluid and be poured into the mould; lastly, the binding material may be used in such small proportion that the product is merely a more or less dry powder, which can be forced into moulds by very high pressure, sometimes with the assistance of heat. Compositions which are either poured or gently pressed into moulds generally fill these latter imperfectly: on drying, contraction takes place, and the contours are deficient in sharpness and more or less rounded. On the other hand, compositions which are pressed into moulds in the form of powder are harder, more durable, and sharp in detail, because the high pressure fills all the minute depressions of the mould and causes them to reproduce their effect in the finished article.

Various Processes.—1. The sawdust of soft woods is boiled with a solution of glue and water-glass, and a further quantity of sawdust is then added and well mixed by kneading, so that a plastic mass of the consistence of dough is produced. This is pressed between iron plates, then dried

and cut up, yielding slabs of any desired size and thickness, which in the dry state are very hard, and fairly resistant to damp. By adding various pigments, such as colcothar, vermilion, umber, etc., coloured tiles suitable for flooring, etc., are produced.

2. A mixture is made of :—

Finely sifted sawdust	7 parts
Powdered rosin	1 part

and placed on an iron plate covered with a sheet of paper. The plate has a rim as thick as the finished slab is intended to be. A second sheet of paper is laid over the mixture and then a hot iron plate, and the whole is placed in a press and exposed to high pressure.

3. The strongly dried and sifted sawdust is mixed to a suitable consistence with a solution of glue, which is so hot that it can be scarcely borne by the hand. The glue solution is made by soaking 5 parts of good pale glue and 1 part of isinglass in water, heating up slowly and filtering carefully. The quantity of water (variable according to the quality of the glue) should be just large enough to prevent the liquid from gelatinising on cooling. In some formulæ gum-tragacanth and whiting are added to the glue solution, the former for the purpose of producing a consistence more resembling that of dough, the latter to give greater hardness. The moulds may be either of metal, plaster of Paris, or sulphur, if oiled; even wooden moulds may be employed if they are first varnished with an alcoholic solution of shellac. A thin layer of the mixture is first pressed into the mould by hand, the mould is then filled up with a mixture made with coarser sawdust, the surface covered with a thick plate and pressed. Before removal from the mould, which is easily done when the cast has dried and shrunk a little, the excess of material is removed by a thin broad knife, so as to give the cast a flat base. Such casts can then be lacquered, gilded, and in

general treated like carved-wood decorations, but in consequence of .the great shrinkage which occurs during the drying they have no sharpness, and do not exhibit the finer detail of the original. These casts require to be protected from damp, but if slowly dried they are fairly free from any tendency to warp.

4. A mixture is made of :—

Glue dissolved in hot water .	10 parts
Ground litharge . . .	4 ,,
White lead	8 ,,
Fine sawdust	10 ,,
Plaster of Paris . . .	1 part

The mixture is poured into oiled two-part moulds, and when cold is removed from the moulds and finished by painting, gilding, bronzing, etc.

5. *Bois Durci.*—This peculiar composition, invented by Latri, of Paris, consists chiefly of fresh blood, mixed with sawdust of hard and resinous woods and pressed by a hydraulic press into iron or steel moulds heated by gas. Under the combined action of heat and pressure the albumin of the blood solidifies to a very hard material, whilst the iron in the blood unites with the tannins of the sawdust to produce a dark colour. If the interior of the mould is greased before filling, the sticky composition does not adhere to it and is easily removed. It is also necessary to press the composition gradually into the mould, since the heat and pressure cause it to shrink considerably. Some salicylic acid is added to the mixture to prevent the blood from putrefying and developing a disagreeable odour. The composition of the mixture may be varied by adding whiting to the blood and sawdust : this obviates the addition of salicylic acid, and confers much greater hardness on the product. An improvement in the process consists in spreading the mixture on heated iron plates, and after drying, grinding it to powder and pressing it into heated metal moulds. Sawdust, especially that of

poplar-wood, is ground to very fine powder, mixed with diluted blood, and dried at 50° to 60° C. This produces a very intimate mixture of the albumin of the blood with the wood-powder. The moulds consist of rings containing matrices of highly polished steel, finely and artistically wrought. The dry powder is filled into the moulds, any excess being avoided, so that after pressing no "fins" are visible. The pressing is done by very powerful hydraulic presses; the moulds are heated by gas, and kept at a definite temperature during the whole operation. The moulds run in grooves, which are so arranged as to prevent any lateral shifting, and are held, by stops, in the proper position for the presses. Each of the hot plates is fitted with gas burners which follow its up and down movement. The gas issues from an annular burner, through the middle of which a blast of air is blown by a fan; the regular heat so produced enables very well-defined castings to be obtained. The consumption of gas is, however, very considerable, but the convenience of the work compensates for the cost. The function of the albumin in this process is not clear. It was for a long time supposed to correspond with that of the varnish on fabrics, but that cannot be the case when the wood-powder, mixed with blood albumin, has first been dried. A closer investigation has indicated the presence of a certain quantity of resin in the sawdust, and resin produces a solid compound with albumin. If the sawdust of a white, non-resinous wood, such as beech, is taken, a hard mass may be produced, but it will have little strength, and will not resist the action of boiling water. If 33 per cent. of blood (blood albumin) is added the mass will be harder, but will fall to pieces after 10 to 15 minutes in boiling water. With 66 per cent. of blood the objects are stronger, browner, and more durable, but are not equal to those from resinous wood. It appears therefore that the blood is not indeed indispensable, but is nevertheless extremely serviceable

in the manufacture. The blood is turned a deep brown colour by the drying, and exhibits glistening specks, which have a good effect in the finished objects. When heated to 170° to 200° C. the blood undergoes an incipient melting, and acquires great adhesive properties. If the mould is opened whilst hot it is found to contain a soft, blackish, semifluid mass, resembling asphalt. It is in this condition, apparently, that it fills all the fine depressions of the mould, which consequently are reproduced accurately after the cast is cold. The product of the whole operation is a hard, wood-like material, which can be worked in every respect like wood itself. Its specific gravity is 1·3, that of the dried mixture of sawdust and albumin being 0·8. This material is worthy of general attention, not only from a technical, but from an artistic standpoint.

6. *Gottschalk's "Hartholz" (Hard Wood).*—Gottschalk of Berlin imitates ebony by means of a composition similar to that of Latri, which he prepares with blood albumin and sawdust dyed black. Finely sifted sawdust of hard woods is boiled for 10 hours with a solution of 8 parts of logwood extract and 1 part of alum in 40 parts of water, then drained and immersed for 5 hours in a bath consisting of 1 part of copper vitriol in 15 parts of water. After removal from the bath the sawdust is put through a centrifugal machine and then dried. It is then mixed with blood albumin, and, in the state of coarse powder, is pressed into heated moulds by a stamping press.

7. *Harrass' Imitation Wood from Cellulose.*—The composition employed by Harrass consists mainly of cellulose, sawdust of soft woods, and an albuminous binding material. The chief feature of this composition is the employment, together with sawdust, of wood-fibre which has been decorticated by chemical treatment, by which means greater durability and strength are secured. Harrass, having failed to get completely satisfactory results when using

merely ground wood-fibre by itself, turned his attention to cellulose, and with this obtained a most admirable composition. The cellulose is prepared by cutting up pine-wood, freed from bark and twigs, into small pieces, which are then boiled with concentrated caustic soda under a pressure of 150 lb. per square inch in large iron boilers. By this treatment the wood is resolved into its constituent fibres. The fibrous pulp is thoroughly washed from the adhering alkali by a stream of water, then bleached by chloride of lime, rewashed and dried. This treatment removes both the natural colouring matters of the wood and those albuminous and gummy constituents which bind the fibres together, and the process of Harrass aims at reuniting the cellulose fibres by the addition of binding materials of similar character.

Cellulose, as supplied by various manufacturers, is in the form of thin, soft slabs, which require to be soaked in water before using the material for the preparation of artificial wood. The excess of water is removed by squeezing the pulpy mass on a fine sieve. A mixture is then made of 4 parts of the cellulose, 4 parts of sawdust, 2 parts of albumin, and 1 part of powdered gallnuts or ground oak-bark; enough water is added to form a stiff paste, and the whole is stirred until thoroughly mixed. The paste is then passed between rollers, which deliver it in slabs about half an inch thick and of any convenient length; it is then dried, first in the air and then in stoves, on frames over which netting is stretched. The dried slabs are now in the form of fairly hard cakes of a greyish-yellow colour. They have the property of softening by heat, and therefore, when compressed into strongly heated metal moulds, they receive, and when cold retain, the impress of the dies.

The metal moulds are hollowed to the desired pattern, and the presses employed are coining presses, worked by a lever or wheel, such as are used for stamping and punching

metals. Larger or smaller presses, and higher or lower pressure are made use of according to the dimensions of the article to be produced. The presses most recently adopted have been on the principle of the stamping mill, driven by gearing, and can be attended to by a single workman. The moulds receive their heat from the tables of the presses, in each of which there are two or three holes, into which gas is conveyed by flexible tubing, to produce the heat. The temperature must be kept uniform by regulating the gas flames, and must never be so high as a red-heat. The temperature is adjusted by observing the melting of certain metallic alloys, and the entire manipulation, simple as it appears, requires the greatest experience and precision. The moulds are either of cast-steel or bronze, and consist of two parts, the matrix and the core, which also forms the cover. The former is hollowed out to the exact shape of the pattern, whilst the latter has only the general contour of the pattern in relief, and when placed on the matrix the space between the two surfaces is exactly of the dimensions which the casting is to assume when complete. These moulds are prepared, by casting, from the design carved or modelled by the artist, and are finished by a metal engraver, to give them the sharpness of detail and smoothness in which the rough casting may be deficient. The moulds for producing the capitals of pillars are made in four or more portions, and require the most exact and careful finishing, which considerably adds to the cost of production. The moulds themselves must have a sufficient thickness of metal to resist the high pressure to which they are subjected. No definite rule for the necessary thickness can be laid down, as it depends on the depth of the matrix and the pressure to which it will be exposed. For small objects a thickness of $\frac{1}{10}$ inch is sufficient, whilst for large ones a thickness of $\frac{3}{5}$ inch may be necessary.

To commence an operation, the empty mould is placed with its cover between the heated table and ram of the

press, and is left there until it has acquired the temperature of the press plates. After the interior surfaces of the mould and core have been thinly and uniformly greased or oiled, the requisite quantity of the finely powdered composition is introduced, the cover is replaced, and the mass is gradually compressed by working the press. The skill and attention of the workman are here called into play, as he has to judge the moment for ceasing to apply pressure, and the time for removing the finished article from the mould. If, when removed, the surface shows imperfections, the object is immediately replaced in the mould, a little composition being added at the imperfect places, and is pressed again. Any excess of the composition escapes between the mould and the core, forming a flat border surrounding the base of the casting, requiring to be removed with a knife or chisel when the casting is cold. The base or back of the object is then ground down on a revolving emery wheel, both to reduce the object to its proper elevation and to form a flat base for securing it by glue or screws. Instead of the emery wheel, a wooden wheel covered with sand-paper or glass-paper may be used. To prevent the freshly pressed objects from warping, it is necessary to lay them, whilst still warm, with their backs resting on a flat plate, and either to load them with weights or to clamp them down and then leave them to get perfectly cold.

In their original state the objects produced in this manner from the cellulose composition are either brownish-grey or yellowish-grey and have a metallic lustre; they can either be coloured in the mass, especially when a black colour is desired, or any desired wood colour, or other shade, can be given to their surfaces by simple processes.

The finished objects require to be kept in dry, well-aired rooms; the damp, musty air of unventilated rooms is as injurious to them as to any other wood-work. They are secured in the same way as wood-carvings; being first

warmed and then coated with moderately thick, freshly-melted, hot glue, and applied to the wood-surface to which they are to be attached, which is also previously warmed. When possible they should be held down with screw clamps until the glue has thoroughly hardened. When glued to polished or lacquered surfaces, the polish or lacquer must first be removed at the places where the moulding is to be attached. It is also very advisable to insert, here and there, small round-headed wood-screws, and in almost any moulding recesses can be found where the screw heads will be out of sight. To obtain as large a surface as possible for glueing, the hollow at the back of the object may be filled up; this is best done by glueing-in a piece of wood which fills the hollow exactly, or the hollow may be filled with a composition consisting of 2 parts of sawdust and 1 part of plaster of Paris, made into a stiff paste with weak glue, and pressed into the hollow after the inner surface has been well brushed over with hot glue. The back is then struck off flat and smooth, and the composition allowed to get dry before it is attached to the surface which is to be decorated. Column and pilaster capitals are best attached by cutting a square tenon, at the top of the wood-column or pilaster, exactly the size of the hollow in the bottom of the moulded capital. The tenon is well coated with glue, and the capital secured firmly by screws. Should any of the objects have become warped, so that the rear surface is no longer truly plane, which is generally due to want of care in storing, the object only needs to be warmed, when it will become flexible, and in that state can be glued in the desired situation and screwed down until the glue has hardened.

By the same means flat pieces can, if desired, be bent to a curved or wavy shape, but the bending must be gradual and carefully performed to avoid fracture. After cooling, the pieces so bent retain their new form. Small irregularities occurring either in the glueing of the pieces to their

supports, or in fitting together the various parts of a moulding, can be rectified, as in the case of ordinary wood, by filing and filling up with some cement. If in fitting the various pieces together any small gaps should be left, these may be filled up with a special wood-cement which is supplied. Corners which do not exactly meet may be touched up with a file. Any smoothing required is best done with fine sand-paper, or glass-paper, but it is advisable first to give the objects a coat of French polish and allow them to dry thoroughly.

8. *Hurtig's Wood-Composition for Parquetry, Blocks, Tiles, and other Decorative Objects.*—Hurtig's process for the production of a wood-composition consists in the manufacture of a waterproof, heat-resisting, compressible powder, and a special treatment of natural wood, together with the preparation of the requisite waterproof binding material for uniting the two. The powder, like that of Harrass, when pressed into heated metal moulds, unites to form a solid substance of any desired shape.

For the preparation of the powder, sawdust of any kind of wood is thoroughly incorporated with a strong aqueous solution of curd soap, and is then thoroughly dried. The powder is then treated with milk of lime and again dried, by which means a material is produced which is quite unaffected by water. To this powder a quantity of air-slaked lime is added, the mixture is then thoroughly saturated with a solution of ordinary water-glass (sodium silicate), and once more air-dried. The water-glass serves as the binding material for the powder, the air-slaked lime being added to produce an insoluble compound with this substance. The dry powder prepared in this way possesses the property of uniting into a solid product when pressed into heated moulds, and is then capable of resisting the action of water, heat, cold, etc.

The following proportions afford serviceable results: 50 kilos (1 cwt.) of sawdust of any kind of wood are

soaked in a solution of 1½ kilos (3 lb.) of common curd soap, with such a quantity of water that the sawdust can be thoroughly wetted with the solution. After drying it is mixed with milk of lime made from 4½ lb. of slaked lime. It is again dried and then mixed with 4½ lb. of air-slaked lime. This mixture is then thrown into a bath prepared with 8¾ pints of water-glass of 33° Bé. strength and a sufficient quantity of water. The thoroughly wetted powder is once more dried, and is then ready for pressing. It yields blocks of stony hardness, which are particularly suitable for laying down parquet floors, as they are unaffected by weather and heat, which is not altogether the case with natural wood. It may also be used for the production of all sorts of household utensils, such as plates, cups, basins, etc. For this purpose the powder is filled into the previously heated moulds and then submitted to pressure; it penetrates into all the depressions of the mould, and on cooling hardens and retains its acquired form.

The pressed blocks may be furnished with a facing layer of natural wood (or any other material), for which purpose they are first coated with the following composition: 2 parts of glue are melted with water, and poured into 1 part of heated boiled linseed-oil; 1 part of resin dissolved in spirit, and mixed with ½ part of turpentine is then added. This mixture is well stirred together in a vessel immersed in boiling water, and is laid on hot. This cement is unaffected by water, and is not liable to the formation of air bubbles. After laying it on the surface of the pressed block it is allowed to cool until it forms a solid crust, and the block is then ready to receive the facing layer. This layer, when the blocks are intended for parquetry, is a mosaic pattern of wooden slabs, and for other purposes may consist of thin plates of copper, brass, or alloy, or of plain veneer or inlaid wood, or of wood with metal fillets, or tarsiatura work of metal inlaid

with tortoise-shell, or composite work of any desired description.

When the upper layer is to consist of wood it is necessary that this should be so treated that it will be waterproof, which is effected in the following manner. A bath is prepared, consisting of 2 parts of concentrated sulphuric acid and 1 part of water, and in this the pieces of wood are immersed. As soon as the liquid has thoroughly penetrated the wood, the latter is well washed by soaking in pure water, rinsed, and dried. It is then immersed in a solution of common curd soap in a convenient quantity of water, and when thoroughly saturated with this solution it is again dried. It is next placed in milk of lime made up with slaked lime and a quantity of water, which is adjusted in accordance with the porosity of the wood, and when the lime has completely penetrated into it, it is once more dried. The wood is now perfectly waterproof, and is ready for employment in the production of parquetry, tarsiatura, marquetry, etc., or for forming the outer layer of any of the pressed objects made according to the above process. To ensure its firm adhesion, it is applied to the surface of the pressed object which has already been covered with the waterproof cement, and the composite object is then replaced in the same heated mould as was used for the compression of the powder. The heat softens the cement, and by a prolonged pressure the outer layer of wood is so firmly joined to the moulded object that after complete cooling the two cannot be separated.

The articles prepared by the above process are said neither to swell nor shrink, neither do they get soft; they also resist the action of moisture and even of rain completely.

9. *Hurtig's Improved Wood-Composition.*—Hurtig more recently improved his process, operating as follows: In the preparation of the powder into forms with a surface exhibiting objects in relief, it is desirable to add materials to the powder which will give it greater plasticity than is

required for objects with plane surfaces. The mode of preparing the powder is varied according to whether high relief or low relief is required.

A. *Preparation of the Powder for Low Relief.*—To the sawdust, which has been treated with soap and milk of lime and then air-dried, a mixture of casein and air-slaked lime is added. The lime and casein should first be allowed to react until they form a pasty mass or liquid. After the sawdust has been thoroughly saturated with this liquid it is air-dried, and is then ready for pressing. Suitable proportions are: 5 to 10 parts, by volume, of sawdust 0·1 to 0·5 part of soap, 3 to 8 of casein which has been combined with 0·5 to 3·0 parts of dry air-slaked lime. These proportions are the limits within which the quantities may be varied; but it is not asserted that these limits are in no case to be exceeded.

B. *Preparation of the Powder for High Relief.*—For the production of objects in high relief, from deep moulds, it is necessary that the powder should not only possess great plasticity, but that whilst warm it should remain flexible in order that it may be removed from the mould without injury, and should harden only when it becomes cold. This is attained in the following manner: Ripe potatoes are dried in their skins, till they have lost 20 to 30 per cent. of their water. They are then crushed, and mixed with fine infusorial earth and a little Burgundy pitch. This mixture is added to the wet sawdust, and after mixing well the whole is air-dried. It is desirable to use unpeeled potatoes in order that the corky tissue of the skins, and the albuminous substances of the layer of cells immediately below the skin, may remain in the mixture. The proportions are as follows: 10 to 30 parts of prepared sawdust, 15 to 40 parts of crushed potatoes, 1 to 5 parts of infusorial earth, and 0·5 to 2·5 parts of Burgundy pitch. These proportions also can be varied if necessary.

The powder thus prepared has not only the high degree

of plasticity required, but even in very hot moulds it retains its original pale colour. Any desired colour can be given to it by the addition of mineral pigments which are not altered by heat, so that in all cases where the outer layer is to consist of metal the colour of the body may harmonise with that of the applied coating. The pressing and other treatment of this powder is performed exactly as described above.

10. *Kletzinsky's Wood-Paste.*—One hundred parts of wood-meal, best that of soft varieties of wood, are well boiled in a solution of 100 parts of aluminium sulphate, and then left to become cold; 50 parts of glue are dissolved in 100 parts of boiling water and intimately mixed with the wood-meal pulp; the paste is rolled out into slabs and somewhat strongly pressed. The slabs, which at first are very brittle, acquire by slow air-drying an extraordinary degree of hardness. As soon as they are hard enough they are moistened with a 5 per cent. solution of potash in water three to five times, and are then finally dried. By this means the individual wood-particles become cemented together by a compound of gelatin and alumina, which is insoluble in water, and when dry has the hardness of horn. If it is desired to produce a coloured paste the meal of raw dye-woods may be used, or any suitable colouring matter may be added, or a mottled appearance may be given by adding variously coloured wood-meal and mixing slightly.

11. *Terra-cotta Wood.*—This artificial product is prepared by Gillmann's process in the following manner: According to the degree of porosity which it is desired to obtain, 1 to 2 parts of sawdust from resinous wood are mixed with 1 part of pulped china-clay and, by the addition of a suitable quantity of water a plastic mass of spongy texture is prepared, which is then submitted to the strong pressure of a steel piston in a metallic cylinder. This produces cylindrical blocks 8 to 12 inches in diameter and 47 to 75 inches long. These are first air-dried, then

dried in a stove, and finally baked at a white-heat in a kiln, and slowly cooled. The blocks are extraordinarily refractory, and are capable of being sawn, cut, planed and polished. Their density is about half that of ordinary bricks. These blocks have great strength, and are employed for architectural purposes.

12. *Palmer's Wood-Composition.*—This material, which is also used as a substitute for wood-carvings, consists of blood, sawdust, bone-dust, and glue. The blood is dried without coagulating its albumin, and is then mixed with a suitable quantity of sawdust, 20 per cent. of bone-dust, and 10 per cent. of glue solution, and is strongly pressed into moulds at a temperature of 120° C.

13. *Billefeld's Artificial Wood.*—C. Billefeld has produced a number of these compositions. That for making casts, by pouring in a liquid state into a mould, consists of a mixture of vegetable fibre, paper pulp, caoutchouc, glue, balsam of sulphur (a solution of sulphur in linseed oil), glycerine, and gluten. Another composition for the same purpose consists of half-stuff (paper pulp), vegetable fibre, tannin-gelatin, gutta-percha, Venetian turpentine, balsam of sulphur, and gum Thus. The tannin-gelatin is prepared by treating glue with the tannin from oak-bark. A third composition, from which billiard-tables and similar articles can be made, is prepared from a paste of 80 parts of water, 32 parts of flour, 9 parts of alum, and 1 part of iron vitriol; then 15 parts of resin and 10 parts of linseed oil are boiled with 1 part of flake litharge, and finally 35 to 60 parts of tow, or, better, wood-pulp, are added. The solid constituents are ground as fine as possible, and the whole paste is well kneaded together and then rolled out. It is then treated with hot linseed oil to render it waterproof. Objects, such as bas-reliefs, chapiters, cornices, etc., were shown by Billefeld in the London Exhibition of 1862. These compositions can be worked up into the most varied articles. One of their applications is the covering of walls,

and for this purpose Billefeld's artificial wood is that mostly employed. Artificial wood presents the very great advantages of resisting the action of fire, of being a bad conductor of heat, and of not being attacked by vermin. Its hardness is equal to that of the hardest woods, it works well with tools, and can even be bent. On this account it has been recommended for making furniture, carriages, etc., and in such cases, to give it the power of resisting the weather, it is soaked in a solution of asphalt. A specimen of such artificial wood was examined by Dr. Sauerwein. It comes into commerce in slabs of about half a square metre, and of different thicknesses. The thickest slabs have a glazed coating of a brownish red colour on one side; three other kinds were without the glazing, but were coated with coarse linen. The grey fibrous composition is fairly hard, so much so that it can only be cut with some difficulty; it cannot be bent much without fracture. Its strength is about that of fir-wood cut across the grain, since it is ruptured by a strain of 640 to 650 lb. per square inch, whilst the breaking strain of fir-wood cut across the grain is 550 to 850 lb. It possesses a slight degree of flexibility, a strip 15 mm. wide, 7 mm. thick, and 312 mm. long, supported at its ends and loaded in the middle, bending about 10 mm. before breaking. It softened when soaked in water, slowly when the water is cold, but very rapidly when hot. The filtered liquid left on evaporation a residue which carbonised on heating, and yielded with iodine the characteristic blue colour of starch paste, so that this substance was probably employed as a cement. Vegetable fibres consisting of refuse tow were easily recognised in the pulped mass. The material burned with difficulty, and without flame; it carbonised and finally left about 33 per cent. of ash, consisting of gypsum, alumina, ferric oxide, and silica. The brownish-yellow glaze contained chiefly ochre, clay, and a little glue.

Another composition consists likewise of large slabs,

but only $\frac{1}{8}$ to $\frac{1}{6}$ inch thick. It is covered on both sides with coarse canvas, and cannot be bent, but breaks when this is attempted. It likewise softens in warm water, giving off a peculiar tarry odour, while the softened mass can also be recognised as made up of the refuse of tow. According to these results it appears to have been made from old rope and sails; hence its tarry odour. The water in which it has been soaked shows also the presence of starch. When heated it carbonises, and on complete combustion leaves about 40 per cent. of ash, consisting of silica, alumina, and ferric oxide, with some calcium sulphate. Clay or cement appears therefore to be one of its principal constituents, so it apparently consists of three main ingredients: 1, plant fibre, such as waste flax or hemp; 2, one or more mineral substances to which the mass owes its form and strength; 3, a binding material, apparently starch paste. In preparing the material it seems to be a point of great importance to have the organic fibres sufficiently finely comminuted, in order that they may be the more intimately mixed with the other constituents, and that the composition should finally have been submitted to powerful pressure.

Attempts were made to imitate the material on the basis of the analysis, by mixing finely chopped tow, plaster of Paris, sawdust, and starch paste. The plaster and clay were finely powdered, tempered with the paste and then mixed with the chopped tow and the sawdust, well kneaded together, and then quickly pressed with a hydraulic press. Equal parts of tow and plaster, with $\frac{1}{2}$ part of clay, or in another experiment $\frac{1}{2}$ part of porcelain cement instead of clay, gave, after drying, a very firm material, closely resembling the commercial one. The glaze was imitated by laying on a mixture of ochre, cement, and glue solution. It is, of course, evident that this small-scale experiment is not absolutely conclusive as to the best materials and proportions for large-scale manufacture.

14. *Ribbach's Sawdust-Composition for Coating Floor-boards, Table-tops, etc.*—Sawdust, or finely ground hard wood, powdered glass, quartz sand or fire-clay, zinc-white, and pigments, are intimately mixed in proportions appropriate to the different objects for which the material is to be used, sifted, and then stirred up with linseed oil varnish. The mixture is then spread, under pressure, on the surfaces to be coated, which previously have been cleaned and rubbed over with varnish, and is smoothed down. The surface may first be divided into compartments by fillets, and the compartments filled with differently coloured compositions. Such a flooring, after it has been well scrubbed with soap, can be waxed and polished.

15. *Wiederhold's Artificial Wood-Composition.*—Wood-pulp, in the form in which it is supplied to paper-mills, is regarded by Wiederhold as a suitable material for making an artificial wood-composition. The simple compression to which this has been submitted confers on it a remarkable degree of hardness, which tends to render its employment difficult, since the wood-pulp cakes, once dried, are only with difficulty softened by soaking in water. The pressed wood-pulp acquires, however, a still greater degree of firmness when it is wetted with a weak glue solution. Wood-pulp takes the impression of the moulds accurately. The pressed articles, after drying, are coated with linseed-oil varnish, boiled to a thick consistence, and laid on boiling hot. By this treatment, which is repeated several times, the articles are rendered completely proof against the action of water; after drying they can be rubbed smooth and polished or painted, and then be varnished. Wood-pulp can be mordanted and dyed any desired tint; the mordant must, of course, be applied before the linseed-oil varnish, or better still, before pressing into the moulds, though this is not absolutely necessary.

The employment of wood-pulp for the manufacture of moulded articles of the most varied kinds should prove more

advantageous than the use of sawdust and blood, and solves the problem of the preparation of wooden articles by pressing into moulds, in a far simpler and more economical manner.

16. *Back and Potin's Artificial Wood.*—Back and Potin of Paris have invented a process for the manufacture of artificial wood, which yields very beautiful products, imitating very closely the different varieties of natural wood. This artificial wood consists of sawdust and glue, which, by treatment with either tannin or alum, has been rendered insoluble in water after drying. In its original pulp form the product can take any shape or impression, and the most practised eye cannot distinguish the moulded objects from actual carvings.

17. *Wood-Composition of Cohnfeld.*—To obtain an artificial wood-composition, Cohnfeld moistens the more or less finely subdivided waste of wood, straw, hay, leaves, bark, etc., singly or mixed, with a solution of zinc chloride of about 1·028 specific gravity, allowing the zinc chloride to act on the raw material until it becomes dry. Thereupon follows a treatment with basic magnesium chloride solution, of specific gravity 1·725 to 1·793, after which the well-mixed composition is pressed into moulds. The composition is left under pressure for 10 to 12 hours, during which time it hardens in consequence of the heat which is developed. The objects are then allowed to dry for several days in a warm, airy place, and are then placed for 10 or 12 hours in a strong solution of zinc chloride, of specific gravity about 1·205, after which they are finally dried. By this treatment it is said that a material is obtained which can be worked just like a hard wood, viz. it can be sawn, planed, bored, and polished, which is fire- and water-proof, unattacked by weak acids or caustic alkalies, not affected by changes of weather, and is therefore highly suitable for architectural or decorative use, with the advantage that it does not warp like wood, but retains its original form unchanged.

18. *Sciffarin* (*Wood-Cement*).—This product is a mixture of sawdust, hemp fibre, starch-meal, gelatinous and mineral substances, the preparation of which is kept secret, but which has been used for the production of ornamental articles. This very strong and elastic composition is capable of taking a high polish.

Woodite.—A composition to which the name of "woodite" has been applied by the inventors, W. Wood and H. Bartlett (Eng. Pat. 17,431, 1901), is made by incorporating together washed Para rubber, Irish moss (*Fucus vesiculosus*), wood pulp, mastic or resin, and sulphur.

Plastic Composition.—The United States Chemical Wood Co., through H. H. Lake of London, have obtained a patent (Eng. Pat. 1838, 1901) for a plastic composition which is composed of about 50 parts of wheat flour, 20 parts of buckwheat flour, and 30 parts of reground plaster. This mixture is incorporated with shredded wood fibre and hot water to form a paste which is then pressed and dried.

Artificial Wood.—According to J. Erdin and A. Erne (Fr. Pat. 326,246, 1902) an artificial wood can be prepared by mixing wood sawdust with various forms of waste material from the colour-making industry. For instance, waste oil colours, varnish foots, fatty oils, etc., may be dissolved in turpentine, and litharge added to it along with a binding agent before admixture with the sawdust. The composition is submitted to considerable pressure in moulds for a period of 5 or 6 hours, after which it is dried at a temperature not exceeding 35° to 45° C. The mixture may be coloured by the addition of pigments, and pleasing effects, resembling marble or wood, may be obtained by mixing with it shavings of variously coloured woods.

Covering for Walls, Floors, and other Surfaces.—In the patent specification of H. J. Haddan, London (Lactoleum Werke Ges. m. b. H. Berlin, Eng. Pat. 6601, 1905), a claim is made for the use of casein, rendered plastic by solution in alkali and reprecipitation with hydrochloric acid, as a

cement for binding vegetable fibre such as sawdust or powdered cork. The material is mixed with oil materials, crude glycerine, and a solution of resin in turpentine and colouring materials, and is then applied to the surface to be coated. After drying the surface is smoothed and polished.

Artificial Stone.—According to the process of O. Westhoff (Ger. Pat. 159,615, 1903) the residues from paper mills, consisting of chloride of lime, alum, caustic soda, vegetable glue liquors, and colouring matters, are mixed together and incorporated with organic matters such as sawdust, cork dust, and also clay, and the composition is moulded, dried, and burnt for the formation of various articles.

Wood Composition.—In the manufacture of a plastic composition which can be moulded F. Matas y Rodés (Fr. Pat. 349,762, 1904) employs sawdust or shavings mixed with a solution of nitrocellulose in methyl alcohol for the purpose of binding the particles together. The material is pressed in heated moulds, which are constructed of perforated sheet metal or wire gauze in order to allow the solvent to escape. Pressure is applied both directly and laterally. Ether or acetone may be added to the methyl alcohol if necessary, while gum arabic, vegetable or animal glue, can be used in place of the nitrocellulose solution as cementing materials.

Plastic Mass.—In the invention of L. Collardon (Fr. Pat. 372,584, 1906) plastic masses are formed from such materials as wood meal, cork, wool or hair, mixed with an acid or alkaline solution of cellulose or viscose, to which is added a proportion of some cementing material such as starch or glue. In order to impart more or less elasticity to the product, such materials as glycerin, acetin, Turkey red oil, or the like, may be employed in addition.

Substitute for Wood, Horn, Rubber, etc. (Eng. Pat. 8478, 1907).—Sawdust or other wood-waste is first of all

treated with size and then steeped in a solution of alum, potassium, bichromate, or salts of a similar character, with the object of reducing the water absorptive power. After drying it is mixed with a binding agent, for instance, with a solution of glue containing potassium bichromate; in addition starchy products, or gummy materials like linseed cake, may be added, together with kieselguhr and a fibrous material. The materials are thoroughly mixed and heated in a closed receptacle.

Wood Substitute.—W. G. F. Siegmann has obtained a patent (Eng. Pat. 15,761, 1907) for a wood substitute which is composed of 1 part of ground straw, 1 part of sawdust, 2 parts of asphaltum, and 2 parts of a binding agent the essential ingredient of which is 2 parts of calcined magnesite, the other constituents being 1 part of boric acid, 1 part of ammonium chloride, and 1 part of colophony. After thorough mixing the material is damped with a solution of magnesium chloride, and then placed under considerable pressure. It will be seen that the cementing material is really oxychloride of magnesium, which sets to a very hard mass. The asphaltum and colophony may help in this respect to a slight extent, but they will also probably soften the material.

Plastic Composition.—In the process patented by B. Lach (Eng. Pat. 6031, 1912) it is proposed to treat wood-meal, sawdust and the like with a solution of an alkali The resinous matter which is thus dissolved is precipitated by an acid, and is then dissolved in a suitable solvent, *e. g.* carbon tetrachloride, benzol, alcohol, or other liquid to form a hot concentrated solution, which is mixed with the wood meal, and the whole submitted to great pressure to force out the excess of the liquid. The composition may be hardened if desired by adding such materials as viscose, glue, or water-glass, but the waste sulphite liquors from paper pulp manufacture are especially useful for the purpose.

The use of the waste sulphite liquors as a binding agent is also claimed by J. Buisson (Fr. Pat. 449,350, 1912) in the manufacture of briquettes, the liquid being evaporated to dryness and then mixed in a steam-jacketed vessel with the wood-waste. The briquettes are heated in a closed chamber at 350° C., and are then allowed to cool therein before being removed.

Artificial Wood.—Wood-waste in the form of sawdust or wood flour, consisting for the most part of cellulose, can be converted directly into viscose by first treating it with caustic alkalies and then subjecting the mass to the action of carbon bisulphide vapours, the quantities of chemicals used being sufficient to convert 1 to 5 per cent. of the cellulose into viscose. Water is subsequently added, and, after thorough mixing, the material is pressed into moulds. After a time the viscose spontaneously decomposes, yielding a deposit of regenerated cellulose which binds the particles into a coherent mass (P. B. Lach Eng. Pat. 12,234, 1912).

CHAPTER IX

EMPLOYMENT OF SAWDUST IN THE MANUFACTURE OF EXPLOSIVES AND GUNPOWDER

In the manufacture of explosives sawdust is used for three distinct purposes: (1) The sawdust is wetted with solutions of various salts, then dried and mixed with substances which, in contact with the salts absorbed by the sawdust, produce an explosive effect. (2) It is used for absorbing nitroglycerine, both on account of its great capacity for absorbing liquids and of the large quantity of gas developed by the combustion. (3) The wood-fibre is converted into pyroxyline by nitrating it with nitric acid, although for this purpose it is usual to employ a purer cellulose than sawdust. In all cases in which sawdust is to be used for absorbing a liquid it must first be perfectly dried, as the presence of any moisture would detract from its absorptive capacity. When sawdust is to be nitrated it is generally first boiled repeatedly with solutions capable of extracting from it, as far as possible, everything except the pure cellulose. These processes, as well as the nitration, being somewhat complicated, require special apparatus; their description lies beyond the limits of the present work, on which account the author confines himself to the mere mention of some of the products, together with a very brief notice of the methods of manufacture.

1. *Sawdust Blasting Powder.*—This explosive is made from nitrate of potash, nitrate of soda, chlorate of potash, sawdust, spent tan, and sulphur, and is prepared in the following manner:—

The nitrates of potash and soda and the chlorate of

potash are dissolved together in boiling water in a pan. After boiling for five minutes the tan or sawdust, or a mixture of the two, is shaken into the solution and thoroughly mixed. The mixture is turned over to a trough, mixed with flowers of sulphur and then dried. If tan is used it is either sifted and only the finer portions used, or it is ground. The blasting powder prepared by this process explodes very energetically, and is suitable for filling bore holes in rock where it is not possible to ram the powder down. This powder explodes by concussion, and on this account there should not be more than 25 per cent. of chlorate of potash present. To prepare a stronger powder, but one which will not explode on concussion, the two nitrates may be dissolved together without the chlorate; after absorbing this solution by sawdust, the boiling solution of the chlorate prepared separately is poured over the mixture, and the addition of sulphur, etc., proceeded with as before. To obtain a slower burning powder the chlorate may be mixed with the other materials in the form of a fine powder instead of adding it in solution. To obtain a weak powder the chlorate or the nitrate of potash, or both, may be omitted.

The proportions for 100 kilos of the mixture are :—

Water	30 litres
Nitrate of soda (Chili saltpetre)	35 kilos
Nitrate of potash	4 ,,
Chlorate of potash	6 ,,
Sulphur	5 ,,
Sawdust or tan	23 ,,

or,

Water	30 litres
Nitrate of soda	15 kilos
Nitrate of potash	2 ,,
Chlorate of potash	3 ,,
Sawdust or tan	25 ,,

For the most energetic explosive the quantity of nitrate of soda is diminished and that of chlorate of potash

increased, adding the latter, either powdered or in solution, to the mixture of the nitrates with the tan.

Another formula which also gives a powerful explosive is :—

Nitrate of potash	10 parts
Nitrate of soda	5 „

These are dissolved in warm water and the solution well mixed with 20 parts of sawdust; the mixture is then transferred to a tray, stirred up thoroughly with 5 parts of powdered chlorate of potash, and lastly, 5 parts of flowers of sulphur are added and mixed in.

2. *Heraklin.*—This blasting powder has already been employed in Austrian and French coal mines : the gaseous products it yields are harmless, and it burns somewhat slowly, so that the rock is merely fractured and not scattered about. According to the English patent of Dickerhoff (Vienna) 10 parts of sawdust, saturated with a solution of picric acid and saltpetre and dried, are mixed with 17½ parts of saltpetre and 7½ parts of sulphur. The solution for soaking the sawdust is made up of 1 part of picric acid and 1 part of saltpetre in 60 parts of water, to 30 parts of sawdust.

3. *Lignose.*—A blasting powder made of wood-fibre (sawdust, ground wood or cellulose) soaked in nitroglycerine is called lignose by Trützschler-Faltenstein; the wood-fibre serves in this case merely for the absorption of the nitroglycerine, instead of the infusorial earth usually employed.

4. *Robandi's Brise-rocs.*—This explosive consists of 40 parts of nitrate of potash, 20 parts of nitrate of soda, 15 parts of sulphur, 1 part of rock-salt, 5 parts of coal, 15 parts of woody substance (sawdust or tan).

5. *Carbazotine.*—The explosive known by the name of carbazotine consists of 50 to 60 parts of potassium, sodium or calcium nitrate, 13 to 16 parts of tan or sawdust, 14 to 16 parts of sulphur, and 9 to 18 parts of soot.

6. *Reynaud's Pyronome.*—For the preparation of this explosive 52½ parts of sodium nitrate are dissolved in the least possible quantity of hot water, 27½ of spent tan or sawdust, and 20 parts of powdered sulphur are stirred in, and the mixture is dried with the necessary precautions.

7. *Poch's Poudrolith.*—A mixture is made of 3 parts of spent tan, 5 parts of sawdust, 3 parts of barium nitrate, 3 parts of sodium nitrate, 6 parts of wood-charcoal, 12 parts of sulphur, and 68 parts of potassium nitrate. The barium and sodium nitrates are first dissolved in hot water, the tan and sawdust are sprinkled into the solution, and the mixture thoroughly dried at a gentle heat. The dried mixture is powdered, and the other constituents, also in fine powder, are intimately mixed with it in a rotating drum.

8. *Volkmann's Wood-Powder.*—This powder is made by soaking sawdust in solutions of yellow prussiate of potash (potassium ferrocyanide) and saltpetre, of which the proportions may be varied, and then strongly drying the product.

9. *Koppel's Safe Blasting Powder.*—Two varieties of this blasting powder are manufactured, the first for hard, the second for soft, rock. Their composition is as follows :—

	I.	II.
Potassium nitrate	35·00	42·00
Sodium nitrate	19·00	22·00
Refined sulphur	11·00	12·50
Sawdust	9·50	19·00
Potassium chlorate	9·50	—
Wood-charcoal	6·00	7·00
Sodium sulphate	4·25	5·00
Refined sugar.	2·25	—
Picric acid	1·25	1·50
Potassium ferrocyanide	2·25	—

Each of the materials is pulverised alone, and they are then mixed in a wooden drum. The mixture is moistened with 10 to 15 per cent. of water and stirred until somewhat

large lumps are formed, which are then slowly dried and freed from dust by screening. The advantages of this blasting powder are its cheapness and its indifference to friction and concussion. It explodes only when brought in contact with burning or incandescent substances.

10. *Diorrexin.*—According to an analysis by Fels, the composition of this explosive is as follows :—

		In 100 parts of dry substance.
Picric acid	1·50	1·65
Wood-charcoal	6·82	7·49
Beech-wood sawdust	9·98	10·97
Potassium nitrate	38·93	42·78
Sodium nitrate	21·07	23·16
Sulphur	12·20	13·40
Water	9·00	—
Loss	0·50	0·55

Equal volumes of diorrexin and ordinary gunpowder exert an equal explosive force, but the fact that diorrexin is 25 per cent. lighter, and costs only three-fourths that of black powder gives it the preference.

11. *Pyrolith.*—Wattlen gives the name pyrolith to a blasting powder of which he makes two kinds : one for hard rock, such as granite, etc., the other for soft rock, such as limestone, coal, etc.

The variety for hard rock consists of :—

Sawdust	12·5 parts.
Potassium nitrate	67·5 ,,
Flowers of sulphur	20·0 ,,

That for soft rock is composed of :—

Sawdust	11·0 parts.
Potassium nitrate	50·5 ,,
Sodium nitrate	16·0 ,,
Powdered charcoal	1·5 ,,
Flowers of sulphur	20·0 ,,

12. *New Dynamite No. III.*—Under this name a blasting powder is now manufactured which is a mixture of charcoal

(or wood-meal), sodium nitrate, and sulphur, impregnated with nitroglycerine. According to Münch the percentage composition is 20 parts of nitroglycerine and 80 parts of a mixture consisting of 75 parts of sodium nitrate, 10 of sulphur and 12 of wood-meal. According to Göhl it contains 12·15 per cent. of nitroglycerine, 13·9 per cent. of sulphur, 56·4 per cent. of sodium nitrate, 13·86 per cent. of charcoal (or wood-meal), and 4·16 per cent. of water.

13. *Kellow and Short's Powder.*—The following formulæ are given :—

	I.	II.	III.
Potassium chlorate	12 parts	6 parts	10 parts
Sodium nitrate	30 ,,	36 ,,	10 ,,
Potassium nitrate	8 ,,	4 ,,	20 ,,
Sulphur	10 ,,	10 ,,	— ,,
Tan and sawdust	42 ,,	50 ,,	46 ,,

The tan and sawdust are soaked in a solution of the salts, the flowers of sulphur are then mixed in and the mixture is dried. According to whether the potassium chlorate is employed in the dissolved or solid state, and in proportion as it is increased or decreased in relation to the sodium nitrate, the powder develops more or less energy.

14. *De Tret's Blasting Powder.*—52·5 parts of sodium nitrate are dissolved in the requisite quantity of boiling water, and the solution is poured on to 27·5 parts of tan, which is thoroughly saturated therewith, 20 parts of flowers of sulphur being then mixed in. The mixture is dried and packed.

15. *Haloxylin.*—Most kinds of explosives contain sulphur; some, however, are made without that ingredient, as for example Fehleisen's haloxylin. It consists of :—

Saltpetre	45 parts
Wood-charcoal	3–5 ,,
Sawdust	9 ,,
Potassium ferricyanide	1 part

The sawdust, charcoal, and saltpetre are intimately mixed, and to each 100 parts there is added a solution of potassium ferricyanide in 2 parts of water, to increase its explosive energy. The mass is then, like ordinary gunpowder, pressed, granulated, dried, and if necessary polished.

16. *Oller's Blasting Powder.*—Oller's blasting powder consists of :—

Potassium nitrate . .	66 parts
Potassium chlorate . .	2½ ,,
Sulphur	20 ,,
Wood-charcoal. . .	3½ ,,
Animal-charcoal . .	2 ,,
Sawdust	6 ,,

17. *Terre and Mercadier's Blasting Powder.*

Potassium nitrate . .	51½ parts.
Sodium nitrate . .	16 ,,
Coal	1½ ,,
Sawdust	11 ,,
Sulphur	20 ,,

18. *Schultze's White Gunpowder and Blasting Powder.*—Thin slices of wood are cut by a stamp into small cubical grains of the size of barley-groats. These are boiled with dilute soda solution to remove the sap-constituents, then washed repeatedly, dried, submitted to the action of bleaching powder and again washed and dried. They are then nitrated with a mixture of nitric and sulphuric acids; the acid is removed by a centrifugal machine; the product is thoroughly washed and dried, then soaked in a solution of potassium or barium nitrate and again dried.

Schultze's powder has greater ballistic energy than common gunpowder, its smoke affects the organs of respiration less, it leaves a very small ash, and it can be stored and transported without the slightest danger, because it can be wetted and redried. Although higher in price than ordinary powder, it is more economical in consequence of its greater efficiency.

19. *Dy's Yellow Gunpowder.*—This product differs from Schultze's only in this respect, that, instead of wood-grains, the ground wood prepared for paper-making is nitrated after granulating. Sawdust may, of course, be used with the same result.

20. *Lanney's White Powder.*—This is a mixture of coarsely powdered sulphur and saltpetre with addition of some form of pyroxyline such as nitrated wood, nitrated sawdust, or nitrated bran. When used for blasting it dislodges the rock without any considerable shattering or scattering. It is difficult to ignite and burns slowly. In hard rock it is more effective than in coal or shale. It is costly to manufacture and gives a suffocating smoke, so that its freedom from danger is its only recommendation. According to analysis it contains 65 parts of sodium nitrate, 13 of sulphur, and 22 of wood-fibre.

21. *Lithofracteur.*—The name " lithofracteur " is applied to certain blasting powders which consist of nitroglycerine absorbed by materials which are themselves explosive When exploded they are converted almost wholly into gases of high temperature and pressure. The absorbing substances are prepared sawdust, coal, bran, etc., and the finished product contains 55 per cent. of nitroglycerine. A previous preparation of the sawdust is necessary, consisting in freeing it from resin and saturating it with saltpetre.

22. *Brain's Blasting Powder* consists of a mixture of potassium chlorate, potassium nitrate, wood-charcoal, and fine oak sawdust, 60 parts of this mixture being then caused to absorb 40 parts of nitroglycerine. Its explosive force is 25 to 30 per cent. higher than that of an equal weight of dynamite.

CHAPTER X

MANUFACTURE OF BRIQUETTES FROM SAWDUST

PAPER-PULP FROM WOOD, AND ITS EMPLOYMENT WITH MORTAR, AND AS AN INSULATING MATERIAL.—Considering the relatively high heating value of sawdust, and the difficulty of burning it in the loose condition in ordinary fire-grates, the obvious method suggests itself of converting it into a compact form by the addition of some kind of binding material, and submitting it to high pressure, so that a handy, clean, compact fuel may be produced. The various binding agents: rosin, tar, water-glass, Iceland moss, etc., which are used for making coal, coke, and charcoal briquettes, may also be used in this case, but as a rule the cost of converting sawdust into briquettes is too high to render any extensive use of the process possible. The conversion of sawdust into briquettes, both for burning into charcoal and for distillation, has, however, been adopted of late, apparently with fairly good results.

One of the most important conditions for the formation of briquettes is that the sawdust must be as dry as possible, another condition being that comparatively powerful presses must be employed for the mixture of sawdust and binding material.

In pressing sawdust into briquettes, G. Grimm aims at obtaining a kind of felting of the material. For this purpose a quantity of the sawdust sufficient to form a thin layer is first pressed into the mould; a further quantity is then added and the pressure reapplied, and so on, until the desired thickness is attained. By this method, in which each

block is built up gradually from thin layers, a very perfect incorporation of the layers results from their mutual interpenetration, thus the product possesses a degree of cohesion which renders it well fitted both for carriage and handling in general. Moreover, when the briquettes are used as fuel, a certain loosening of the layers is brought about by the heat, so that the whole mass is brought into a state of combustion more rapidly than would be the case if its texture was uniform throughout. This property is also valuable when the briquettes are submitted to dry distillation, since the volatilisation of the products of distillation proceeds more rapidly and uniformly throughout the whole mass of the briquette than is the case with those prepared by the usual processes.

Amongst the newer processes for the manufacture of briquettes may be mentioned that in which the waste liquors from the manufacture of sulphite pulp is utilised. The sawdust—also small charcoal and charcoal powder—is mixed with the inspissated waste lye by a mixing machine, very serviceable briquettes being obtained by pressing the mixture. The briquettes produced have a sightly appearance, are firm, coherent, and do not become damp as would have been expected from the hygroscopic character of the dry residue of the lye.

According to Meyer, waste or comminuted wood is steamed until its elasticity is destroyed, and the blocks obtained by pressing it are then submitted to distillation, whereby, it is stated, a very solid charcoal is obtained.

Pfropfe prepares briquettes from 2 parts of small wood and 1 part of tar, by shaping the mixture, either by hand presses or mechanical presses, into blocks or bricks, which are then distilled. The condensable products of distillation separate automatically into aqueous and oily layers. The residue in the retort is said to be pure charcoal.

Petroleum Briquettes with Sawdust.—Rosin is dissolved in petroleum by stirring or shaking; and during

this operation, which takes about 40 minutes, finely powdered caustic soda, or other alkali, is gradually added. At the same time dry sawdust, or some similar absorbent material, is put in. The soda may be crushed under petroleum to prevent it from taking up moisture from the air. Powdered soda which has been slightly moistened with water may indeed be used, but the quantity of water must not be large enough to make the soda pasty. The operation is conducted in a receptacle furnished with stirring, or better with shaking, machinery. After thorough blending the mixture is removed from the receptacle and very soon becomes solid.

Sawdust Briquettes with Molasses.—Molasses is a very suitable binding material for the production of briquettes from sawdust, small charcoal, and charcoal powder. Salterey describes his process, which can be employed for any combustible material, or even for ores, as follows : Experiments have shown that all kinds of sugar-molasses, whether dialysed or not, may be used for the purpose. The process is a very simple one. The sawdust, from which coarse fragments of wood should be removed, is dried until at least the greater part of the moisture is expelled, and then moistened with diluted molasses and thoroughly amalgamated in a mixing machine, such as is commonly employed for the manufacture of briquettes. The quantity of the binding material must be adjusted according to the dampness of the sawdust, only so much being added as will make the mixture feel moist. After the requisite blending the powder is strongly compressed into moulds, and the bricks are allowed to dry for some time in airy situations before they are put to use.

Sawdust Briquettes for Distillation.—In order to use up wood waste most advantageously it is desirable to convert the loose, pulverulent material into a compact condition, and for this purpose the briquette form is the most appropriate and obvious. Amongst the newer

processes which endeavour to solve the problem in this manner may be mentioned that of Bergmann, according to which the sawdust, after thorough drying, is merely compressed by strong hydraulic pressure into the form of solid briquettes. This proved impracticable, even with a pressure of 300 atmospheres (2 tons per square inch), without previous heating to 130° C. A new patent prescribes a pressure of 1000 to 1500 atmospheres (6⅔ to 10 tons per square inch), but it is obvious that the use of such enormous pressures is not only attended with many difficulties, high cost, and frequent repairs, but also with considerable danger and inconvenience.

F. Arnold of Magdeburg has constructed a toggle press, in which, by means of a steel lever, a very high pressure can be obtained with a relatively small expenditure of force, and with which both sawdust and shavings can be compressed into solid blocks, convenient either for burning or carbonisation.

According to a patent taken out by E. Leinhaas of Freiberg in Saxony (Ger. Pat. 86143) the preparation of such briquettes may be accomplished, without either high pressure or heat, by using the lime-sludge residue from the distillation of acetic acid as a binding material for sawdust.

Waste vegetable substances, sawdust, tan, etc., are air-dried and then mixed with the lime-sludge in simply constructed mixing machines. The mixture is made into briquettes by either screw presses, or other well-known briquette presses—the adoption of the special form of press depending on the daily output required—and is then carbonised in a special apparatus (Ger. Pat. 30338), the gases being passed through a chamber in which the briquettes were stacked up before the fire was lit, and working at first at a low temperature. The tar-vapours are precipitated on and are absorbed by the briquettes. The temperature is then gradually raised, whereupon the more volatile portion of the tar is driven off, whilst the heavier

constituents of the tar carbonise in the interior of the briquettes and bind together the particles of wood. Simultaneously with the distillation products from the sawdust, etc., acetic acid is evolved from the lime-sludge, chiefly in the form of acetone. The gases are freed from acetic acid, acetone, tar, etc., by cooling, and the permanent gases are used for heating. The carbonisation is at an end as soon as the gases are found to be free from condensable products: and the time required is easily judged after some experience. The carbonised briquettes are cooled somewhat in the furnace, and are then transferred to air-tight cooling chambers. These charcoal briquettes form a far more valuable combustible than ordinary wood-charcoal, furnishing an incandescent fuel such as is required for heating railway carriages, flat irons, etc. Such a fuel was formerly obtained by powdering wood-charcoal, mixing it with soda, pressing into moulds and heating to redness. By the above process, however, the incandescent fuel is obtained direct at the first carbonisation, and the chief difference is the introduction of lime from the lime-sludge instead of soda.

In the manufacture of briquettes from wood-waste the material is ground to a fine state of division and mixed with sufficient of the evaporated lyes from the manufacture of wood pulp to make it cohere. The material is then pressed in suitable moulds and the blocks carbonised in closed chambers at a temperature of 350° C. The briquettes are cooled down out of contact with air to prevent them taking fire (J. Buisson, Fr. Pat. 449,350, 1912).

Employment of Sawdust in the Ceramic Industry and as an Addition to Mortar.—The utilisation of sawdust in the manufacture of pottery rests upon its property of lightening clay—the specific gravity of sawdust being very low—and of carbonising or burning away completely to an ash during the subsequent firing, in consequence of which a further lightening, accompanied by porosity, is produced.

It is, for instance, in this way that the Alkarazzas, those porous clay bottles formerly used by the Arabs for cooling water, which have continued in use in Spain and have lately been introduced into Germany, are made from clay with which fine sawdust has been mixed. During the baking of the vessels the sawdust is burnt off, the clay being left with a multitude of minute pores, by means of which the water oozes through the walls. On the exterior of the vessel the water evaporates and, by rendering a certain amount of heat latent, keeps the contents cool.

In the same way porous plates are manufactured for drying substances containing much water, as, for example, starch. These plates are capable of absorbing much larger quantities of water than merely unglazed earthenware.

For building purposes bricks of greater or lesser porosity can be obtained by the addition of a larger or smaller proportion of sawdust to the brick-earth. When such bricks are used for house walls, they produce much warmer rooms than do common bricks, because the air in the pores is a poorer conductor of heat than the clay. Moreover their weight is considerably less than that of ordinary bricks, and they can therefore be used for the construction of fireproof walls in situations where a heavy weight is inadmissible, or for building arches which will bear less heavily on their abutments. The use of such bricks is of high antiquity; in ancient Rome pumice was used in making them, but where that was not procurable clay was mixed with substances which became consumed whilst the bricks were being burnt.

Sawdust is particularly suitable for this purpose, since the pores can be made larger or smaller according to the coarseness of the sawdust; moreover, it burns away at a low temperature, leaving no detrimental residue, since the small amount of potash which the ash contains can have no injurious effect on the quality of the bricks.

A very modern product is the cement composition used

for light partition walls, for plastering ceilings, etc. It is prepared by mixing cement or plaster of Paris with sawdust in various proportions, and casting the mixture to form planks, or mouldings, either with or without a reinforcement of wire netting. The use of sawdust as an addition to mortar for stuccoing the fronts of houses, etc., is well known, such mortar finding various applications. For plastering walls and ceilings, and in damp rooms, Rohde employs a mortar composed of freshly slaked lime and the sawdust of soft wood, which should be in as fibrous a condition as possible. The quantity of lime should only be just sufficient to render the mixture workable. This mortar forms a felt impregnated with lime, and is so light that, if struck, the injury does not extend beyond the spot on which the blow falls; whilst a coating of it which was laid on an extremely damp wall showed no change in solidity or in appearance in the course of eight years. Rohde specially recommends it for plastering mud walls and pisé work, as well as for roofs coated with clay. Even on the plank-walls of an ice-house, against which the ice was packed tight, a plaster coating of this material $\frac{2}{5}$ inch thick adhered firmly and remained sound. Rooms which have had their walls plastered with this composition can be papered in a few weeks.

Two American inventors have proposed to use sawdust instead of sand in stucco and wall plaster, in order to lighten the mixture and secure firmer adhesion to the wall. An old practice was to use sawdust for covering up objects exposed to rain, cold, etc.; one of these patents proposes simply the use of a mixture of equal parts of sawdust and plaster of Paris or cement; the other gives the following:—

Mixture of slaked lime and sawdust .	45 parts.
Plaster of Paris.	10 ,,
Glue	$2\frac{1}{4}$,,
Glycerine	1 part.

Addition of Sawdust to Mortar.—By the use of sawdust the formation of cracks in wall plaster may be prevented, and on this subject the following statement has been made :—

" The house in which I dwell lies very high and exposed, so that the copious rain, which here, in the neighbourhood of the sea, falls almost continuously during the equinoxes, fills with water every chink in the outer cement on the weather side of the house, especially on the upper surfaces of the breast-mouldings and plinth-mouldings. These crevices are then gradually widened and extended by the formation of ice, so that in the spring large surfaces of the cement peel off. To remedy this inconvenience, which annually recurred in the same situations, and which was the more expensive and troublesome because the freshly stuccoed surfaces always required painting with oil, I had employed the most varied means without success, when the idea occurred to me to prevent the formation of crevices in the stucco by the addition of sawdust, which I expected to have a felting action similar to that of calf's hair. The sawdust was strongly dried, and then passed through a common fruit sieve to remove coarse chips, so that only the small woolly flocks were used. I made up the mortar with 1 part of cement, 2 parts of lime, 2 parts of sawdust, and 3 parts of sharp sand. The sawdust was first thoroughly mixed with the cement and sand and then the lime added. This had the desired result, for since that time no crack has shown itself even in those joints which were not bonded together, although, in the finishing cement-coat of these, sawdust could, of course, not be used." Sawdust therefore fulfils the purpose of matting a plaster, so as to prevent it from cracking, far better than hair, and in such cases as the foregoing is strongly to be recommended.

Quite recently a commencement has been made in the use of sawdust as a non-conductor of heat, by mixing it with plaster of Paris, loam, mortar, hair, cork, etc., and

applying a thick layer to steam pipes, cylinders, heaters, etc., round which cloth has first been wrapped, and giving it a coat of oil paint when dry.

Stony Composition from Sawdust for a Building and Insulating Material.—This invention relates to a stony composition which should be particularly suitable as a building material for the construction of walls and flooring, for making rooms damp-proof, for paving-stones, for building reservoirs and for vessels of every kind. It consists principally of wood-meal and plaster of Paris, or cement. The wood-meal requires to be so prepared that it will unite intimately with the plaster or cement; it also needs to be made incombustible and prevented from absorbing moisture. The proportions used are: 2 parts of wood-meal to 1 part of plaster or cement.

The wood-meal requires boiling for a long time with water-glass, powdered asbestos, and a little glue or other binding material, in order that the fine particles may be thoroughly penetrated by the water-glass, and coated with the asbestos. Thus prepared, the meal is not only incombustible and non-hygroscopic, but, as already mentioned, is particularly capable of uniting with plaster of Paris to form a homogeneous mass of great hardness, such as has not hitherto been obtained with wood-meal.

The prepared wood-meal is mixed with plaster or cement and water and is poured into a mould, in which, if desired, wire netting may previously have been placed. For purposes where maximum strength of material is desirable, the contents of the mould may be exposed to pressure whilst hardening.

After the mixture has hardened, the slabs or other objects are baked in a kiln, or are dried in a stove specially constructed for the purpose.

According to the uses to which the product is to be put, sand, tar, asphalt, and other substances may be added to the wood-meal after boiling with water-glass.

The material obtained by this process is light and of low porosity; it has the great advantage of not being hygroscopic or permeable to moisture. Walls built of this material may have nails driven into them without any damage to the surrounding parts, whilst the nails hold well on account of the firmness of the substance. Moreover, in consequence of the treatment of the wood-meal with water-glass and asbestos powder, the material is fireproof. The addition of tar acts also as a protection against vermin, rotting, and the growth of mould.

The hardness of the substance and the other properties mentioned render this material peculiarly fitted for paving-stones. It lasts well, deadens sound, and does not wear out the horses' hoofs.

This material is also a low conductor of electricity, and is therefore suitable for use as an insulator.

In comparison with the well-known practice of coating wood with water-glass to secure a better adhesion of plaster, it should be borne in mind that, in the new process, each particle of the wood is thoroughly saturated with water-glass by the process of boiling the sawdust in a solution of that substance.

Manufacture of Paper-pulp from Wood (Sawdust, Shavings, etc.) for Paper-making.—In the employment of wood for paper-making the object is to obtain a cellulose as pure and as long-fibred as possible; sawdust, however, furnishes only very short fibres; moreover, it is so bulky that the boiling, or at least the circulation of the liquid in the boiler, is much impeded.

The apparatus described below is intended to overcome this difficulty and to render possible the production of a serviceable wood-pulp from sawdust, shavings, and waste pieces of wood 2 to 3 inches thick, by a combined boiling and grinding process. The apparatus represented in vertical section in Fig. 43, and in horizontal section through the line *a*, *a*, by Fig. 44, consists of a steam-tight

cylinder, A, which has a smooth inner surface and in which there rotates a central axle, H, carrying a number of forked plates, *d*, *d*. The forks are provided with adjustable journals, which are connected with the adjusting screws, N, N, by springs. In these journals revolve the axles, P, of the rollers, K, which the rotation of the shaft, H, causes to roll round on the inner surface of the cylinder, A, and to exert upon that surface a greater or smaller

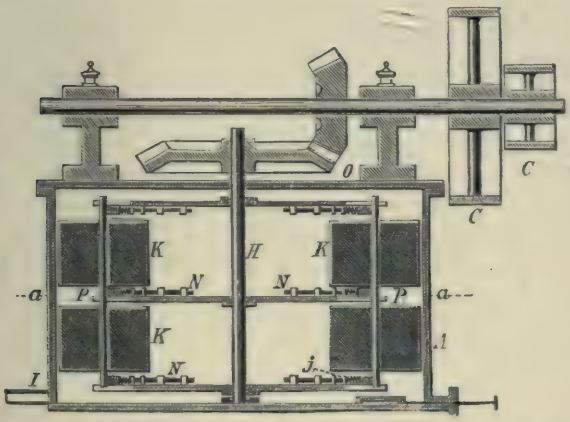

FIG. 43.—Apparatus for Preparing Paper-pulp from Wood Waste (Vertical Section).

pressure according to the centrifugal force developed by a higher or lower speed of rotation.

Instead of the bearings with springs, the construction shown in Fig. 45 may be adopted. Here the rollers, K, are bored out and ride loosely on the axles, P, fixed to the arms, J, so that they press against the interior of the cylinder, A, solely by virtue of the centrifugal force developed by the rotation, and in doing so take up a more or less eccentric position with regard to the axles, P. The process is as follows: Through a manhole in the cover of

the cylinder an appropriate quantity of sawdust, shavings, or wood-chips is introduced, water being added in quantity sufficient to float the charge of wood. The manhole is

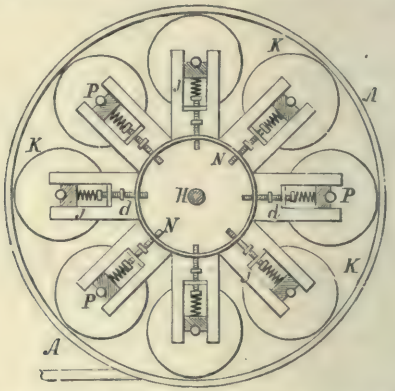

FIG. 44.—Apparatus for Preparing Paper-pulp from Wood Waste (Section through the line *a*, *a*).

closed, and through the tangential pipe, I, steam is admitted at a pressure of at least 52 to 53 lb. per square inch. The steam throws the mixture into rotation, heats it up,

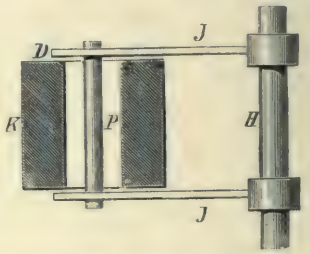

FIG. 45.—Modified Apparatus for Preparing Paper-pulp from Wood Waste.

and produces a pressure in the cylinder. This treatment causes the fibres to acquire a degree of tenacity which prevents them from breaking off short during the subse-

quent action of the rollers. Some lime, soda, or potash may be added to the mass at the outset, to render the fibres more pliant and free them from all impurities. The mass remains exposed to the action of the steam until the fibres have acquired the requisite toughness and pliancy. This generally takes two hours, after which for another two hours the mass is gently worked with the rollers. The main shaft, which drives the axle, H, by bevelled gearing, is fitted with pulleys of two sizes, C, C, to give two different speeds. By running the shaft with the large pulley, a slow speed and light pressure on the interior of the cylinder are obtained. The rollers are arranged so as to bear upon almost the whole surface of the cylinder. Either a single long roller, or several superposed short ones may be employed. By reason of the yielding of the springs, the rollers are able to pass over any hard portions of the material without injury to the machinery. After the machine has been driven for two hours at a slow speed, the driving-belt is shifted to the small pulley whereby the rollers are set in rapid rotation. This throws the wood outwards towards the walls of the cylinder, where the fragments become progressively crushed and disintegrated, without, however, any breaking up of the fibres themselves; and, as the pressure of the rollers on the cylinder is considerable, and the fragments of wood pass under them again and again, the individual fibres are at last completely separated one from another. The process may be conducted without the addition of any alkali, the action of the steam being relied on to produce the requisite toughening of the fibres. In that case, however, the operation requires a much longer time.

KAPP'S WOOD-PULP.—The wood-pulp obtained when wood is ground by millstones with addition of water is essentially different from cellulose. It is merely wood reduced to a fine state of subdivision, the fibres being still coated with the incrusting substance, and may be used as

an addition to paper-pulp and rags in making common pasteboard. To grind waste wood and tan (but not sawdust) to wood-pulp, W. Kapp of Berk-on-the-Lippe uses a stone mill with horizontal rolls, above which is fixed a feeding-box fitted with plungers. The material to be ground is filled into the box below the plungers, the latter being meanwhile raised by a hand-wheel engaging in a pair of racks, which when raised are fixed by a ratchet. When the ratchet is released the plungers are depressed by a counterpoise. The lower edges of the feed-box should not actually touch the stones, but the intermediate space must be as small as possible: should it become increased by wear, the position of the box may be adjusted by means of screws, even while the machine is running. To prevent the wood-pulp from flowing over the ends of the stone rollers wooden cheek-blocks are fitted close to the stones. Whereas, in ordinary mills, the use of hard stone is inadmissible, since such stone would produce an inelastic, brittle material, in Kapp's machine it is advantageous, the disintegration process being different, because the material has already been partly reduced in size; and much finer fibre is produced.

The stone requires to have a peripheral velocity of about 1640 per minute. The water required is supplied by a pipe as in an ordinary wood-pulping mill.

CHAPTER XI

VARIOUS APPLICATIONS OF SAWDUST AND WOOD-REFUSE

SAWDUST AS A MATERIAL FOR PREVENTING ROUGH CAST FROM FLAKING OFF UNDER THE INFLUENCE OF FROST AND RAIN.—Sawdust should serve very much better for this purpose than the hair commonly employed. It must first be well dried, and sifted to remove all coarse particles. A mixture is then made with 2 parts of sawdust, 5 parts of sharp sand, and 1 part of cement, which are thoroughly commingled, 2 parts of lime being then added.

MANUFACTURE OF CASKS FROM THE WASTE WOOD OF SAW-MILLS.—The outside planks of tree trunks, which are obtained as a refuse product when cutting the timber into deals, are cut lengthways by an ordinary circular saw, and each of the pieces is reduced to the length required for the cask staves. Each of these pieces is again cut to the proper width by a multiple circular saw, to which the wood is fed by means of grooved rollers. Lastly, a circular saw, with verticle spindle and automatic feed, cuts the pieces to the size required for the staves. This saw has a diameter of about 23½ inches. In the middle of the spindle, above the saw-bench, there is a guide rod, at each side of which a grooved feed-roller is situated, by this arrangement enabling two pieces of different thickness to be cut simultaneously. These pieces are then conveyed to the trimming and chine-cutting machines, in order to have their ends cut to the right bevel and the chine notches cut out for the reception of the cask heads. This machine has a shaft carrying the knives for cutting the chine notches,

and two shafts for the trimming saws. Both the trimming saw and the notching knives can be set to the proper distance apart for staves of any required length.

The staves are fed into the machine by hand, each stave being laid with its rear edge on a rod which moves backwards and forwards in guides. The pieces so trimmed are now conveyed to the jointing saw, a machine with a small strong circular saw, to which the pieces are brought upon a carriage which runs on rails. This machine gives the edges of the stave their exact bevel, no hand work being afterwards required to fit them together. To save freights the casks are not made up, the staves and heads for each cask being tied into a bundle. The heads are cut out in the same fashion from shorter waste pieces, and from pieces not suitable for staves. The head pieces are dowelled and cut to the circular form by a special machine. All the machines can be fed by boys. One set of machines will turn out several hundred casks a day. The demand for these is almost unlimited, since the users of such casks —cement makers, millers, nail makers, and fruit merchants —are always ready buyers.

Manufacture of Calcium Carbide from Sawdust.—For the manufacture of calcium carbide, from which acetylene gas is prepared, by the action of water, either coke coal, or wood-charcoal may be used. According to a patent obtained by Wilson of Ontario, the charcoal of sawdust and other wood-refuse can be employed. These substances are carbonised by heating in suitable furnaces, and the finely powdered charcoal is mixed with limestone. The mixture is then exposed for 10 hours to the heat of an electric arc which is sufficiently powerful to melt iron and boil lead. The product is calcium carbide, which, reduced to small fragments, is supplied to consumers in this form in tin canisters.

Sawdust as Manure.—Sawdust, by itself, has but little value as a manure, because it is non-nitrogenous, and

even when decomposed in the soil by atmospheric influence is incapable of furnishing any nitrogenous materials to vegetation. Though its value as a manure is far less than that of straw, it would be incorrect to regard it as altogether valueless. Since although the amount of phosphoric acid and potash in the wood of coniferous trees is extremely small, nevertheless, in the soil, sawdust is rapidly converted into humus which, for many varieties of soil, has at least some value. On the other hand, however, it must be remembered that the pure wood-fibre such as that present in wood-meal is a particularly stable substance, very indisposed to rot spontaneously, and therefore decomposes so slowly that the carbonic acid it generates is supplied far too gradually to have any marked effect on the vegetation with which it is in contact. If therefore we disregard its mechanical effect, its manurial value is almost negligible. Its mechanical action, especially its great capacity for absorbing liquids, is however so considerable, that, from this point of view alone, it deserves notice, and as a matter of fact, sawdust is largely used as a mulch. The practice, therefore, which has been frequently recommended, of mixing artificial manures with long-fibred, woolly sawdust, and throwing the mixture into heaps to undergo fermentation, is by no means to be rejected. One of the great advantages of this method is that the powdery manure when applied at a particular spot does not get blown all over the place; moreover, the decomposing sawdust ought to render the manure more soluble and more rapidly active.

1. *Richardson's Artificial Manure.*—For the preparation of his artificial manure, Richardson employs dry sifted sawdust, which he moistens with hydrochloric or sulphuric acid and then heats to 130° F. The mixture is either spread on the land as it is, or is mixed with blood and heated to 140° F., which causes the blood to coagulate. The dry mixture can be packed in sacks, distributed to

consumers, and used as manure. Instead of blood, bone-ash, coprolites, animal charcoal, or natural phosphatic minerals, such as phosphorite, etc., may be added to the mixture of sawdust and sulphuric acid. The mixture is thrown into heaps which are then covered with straw, old sacks, etc., whereupon, by chemical action, a heat of 100° to 150° F. is developed inside the heaps. When the temperature of the heaps has fallen to that of the surrounding atmosphere the process may be regarded as completed and the product be put to use.

2. *Carbonised Sawdust as Manure.*—For utilising sawdust in agriculture it is most advantageous that it should be carbonised. With this object charcoal heaps are constructed first by making a heap of brushwood, such as broom and other dwarf shrubs, which is gradually filled up with sawdust, thrown on lightly with the shovel in such a way as to leave numerous gaps for the admission of air. When the heap is covered with a layer of sawdust, which must not be too thick, the fire is kindled. Wherever the fire begins to break through, more sawdust is thrown on, and when the layer has reached a certain thickness the heap is allowed to cool. After complete cooling the heap is taken apart. The charcoal obtained in this way is mixed with liquid manure, urine, phosphates, blood, etc., piled up in heaps, and left to itself for some weeks. The sawdust must, of course, be dried before being carbonised, and the operation must be carried on in a dry locality. This manure has given excellent results with a variety of plants.

3. *Manure from Tan.*—1. The production of the manure depends on fermentation, and for the formation of the compost heap it is desirable to select a place exposed to air and moisture. On the spot selected, a layer of tan about 14 inches thick is spread out, this being covered with $2\frac{1}{2}$ inches of slaked lime; above this a second layer of tan is spread, and likewise covered with lime, the heap being

built up in this way with alternate layers to a height of about 6½ feet. The heap is moistened with water until it heats strongly, the bark, which, on account of the tannin it contains, does not readily rot by itself, is brought by the agency of the lime into a decomposed condition. If it is desired to obtain a strongly forcing manure, a layer of powdered gypsum (*Terra alba*) is spread upon the lime, then one of fresh, undecomposed horse dung, then tan again, and so on to the desired height. Liquid manure and urine are then poured into holes made by thrusting a stake into the heap, and the whole is left to rot.

2. The following mixture also gives an admirable compost: 10 parts of well-manured garden soil, 2 parts of gypsum, 1 part of quick-lime, ¼ part of rock-salt, 2 parts of wood-ash, 1 part of tan. The whole is well mixed, and laid out in a long ridged heap. Whilst mixing, strong liquid manure (drainage from the dung heap) is added as long as it can be absorbed without causing the mixture to cling together. The heap is turned over and moistened with liquid manure twice a week for a month. It is necessary that it should heat up if it is to prove an efficient forcing manure. The heating is due to the tan. If tan is not obtainable, the dust or refuse from threshing clover seed, rye, wheat, or buck-wheat may be used instead; also malt dust, fir sawdust, etc., may be taken. The heap will begin to heat within 24 hours, and if turned over regularly and moistened twice a week it will be fit for use in a month.

Wood-Mosaic Plaques from Wood-Shavings.—The curled shavings obtained in planing wood are flattened out by hand, after soaking in water or steaming, being laid one on the other and gently pressed for some time. They thus become perfectly flat and can be easily and rapidly piled up in regular layers, after being first dipped in thin glue. Care must be taken that the heaps are built up perpendicularly, with which object the thin and thick

parts of the shavings are alternated. The block thus obtained should be pressed until the glue is perfectly dry, and will then form a solid mass, the thickness of which depends on the width of the shavings, and its other dimensions on the length and number of the shavings employed.

These blocks can be planed smooth on the surfaces which exhibit the edges of the shavings, whereupon several of them can then be glued together. The planed surfaces have a very agreeable appearance, enabling mosaic patterns of a very special character to be constructed. With this object the shavings are dyed with various colours before they are glued together, care being taken that the dye penetrates the shavings thoroughly; and then, after being dipped in glue, the differently coloured shavings are alternated when superposing them one on another.

By this process very pretty wood-mosaics can be produced, which show fine, variously coloured veins; they are specially suited for inlaid work and for many other purposes.

Bottle Stoppers made from Wood-Shavings.—These can be prepared as follows : The shavings are wound round a short cylindrical rod of wood, both the rod and the shavings, as well as the exterior of the composite plug, being smeared with a resinous or caoutchouc cement. The rod should be of the same length as the width of the shavings, and should have a solid handle by which the stopper can be drawn from the neck of the bottle or jar.

The stoppers are finally immersed for half their length in melted paraffin wax, and are then ready for use.

Employment of Waste Wood from Saw-mills for Parquetry.—Parquetry blocks are generally either 23 or 25 inches square. Nowadays, the base blocks for veneered parquetry are prepared as follows : Pieces somewhat shorter than the block to be made are glued together, cut to size, and fillet pieces attached to their ends by grooving

and tonguing. In Russia a special method is in use. The base block is formed of a frame, two cross rails, and four panels, and the frames are furnished with holes and dowels by which they are fitted together. The four panels are tongued and grooved into the rails and frame, thus only the dowels require to be glued. The panels are so arranged that the grain of one runs at right angles to that of the other. This renders any warping of the block impossible, the shrinkage at the same time being reduced to a minimum, since only the two frame pieces, which lie parallel to one another and have a total width of not more than 10 inches, are capable, even under the most unfavourable variations of temperature, of slightly swelling or shrinking. Any waste pieces of wood may be used for making these base blocks, since the panels are at most about 8 inches long. By using a circular saw and a simple drill for boring the holes, these blocks can be made with the greatest ease.

Wooden roof-shingles are still saleable articles, and are easily and cheaply cut out with a circular saw.

Fire-lighters from Sawdust and Shavings.—Fire lighters, which can be used for rapidly kindling any kind of fuel, are made from sawdust or shavings impregnated with rosin. The sawdust-lighters are made by melting the rosin (the cheapest, darkest quality) in an iron pot, adding the requisite quantity of sawdust gradually, and thoroughly mixing it with an iron rabble. The sawdust must first be thoroughly dried or the rosin will froth up considerably. The mixture is next spread out on a moulding bench which has been well oiled, a well-greased roller being passed over the mass, thus pressing the mixture into the furrows in the bench whilst at the same time reducing it to the proper thickness. The individual fire-lighters can then be separated from one another, by breaking the mass at the indentations, and be packed and sent to market.

Fire-lighters of another kind consist of shavings, which are unrolled, dipped into melted resin, and rolled up again.

Manufacture of Carborundum from Sawdust.—Carborundum is prepared by fusing in the electrical furnace a mixture of coke and sand, to which a little common salt is added to increase its conductivity, and some sawdust to render it porous and furnish an outlet for the gas evolved (carbon monoxide), thus preventing explosions.

The dimensions of the furnaces are 106 by 22½ by 22½ inches.

The older practice was to establish an arc between the poles; at the present time a cylindrical rod made of coke-powder is laid between them, and this being a bad conductor is raised by the current to an intense white-heat, which enables the process to be conducted much more economically. The production of 1 lb. of carborundum requires at the present time about 6½ horse-power. The current supplied by the Niagara Falls Power Co. has a tension of 2200 volts, and is stepped down to one of 185 volts by a transformer, which was the largest in the world before the installation of the one at Buffalo. The efficiency of the transformer is 96 per cent., therefore out of each 1000 horse-power 40 are converted into heat, so that ample cooling appliances have to be provided. The thick oil with which the transformer is filled is cooled by a spiral water pipe, and is kept in constant circulation by a pump.

The course of an operation is thus described in the Journal of the Franklin Institute: During the first half-hour after charging the furnace and turning on the current, nothing is to be observed; a peculiar odour is then developed, and the gas which escapes through the crevices in the furnace can be kindled. After three to four hours the walls and the upper part of the furnace are completely surrounded by the light-blue flame of the carbon monoxide produced from the coke and the oxygen of the sand. After

four or five hours the crown of the furnace begins to sink in, and cracks open through which yellow sodium flames escape. It frequently happens that the uppermost layer is not sufficiently porous to allow the carbon monoxide to escape freely: a rent is then formed suddenly, a puff of burning gas escapes, and a small crater is instantaneously formed which throws out white-hot ashes, a blinding yellow flame, and a thick smoke which fills the whole workshop. In such cases it is often necessary to shut off the current and allow the furnace to cool slowly, so that the faulty part can be removed later on and filled up afresh. After 24 hours the current is shut off, and the charge of the furnace is cleared out down to the amorphous outer layer of carborundum. This fritted crust, which surrounds the core, is broken away, the crystallised carborundum being found inside. This is reduced to powder of different degrees of fineness by levigation, much in the same way as emery. Its price is from two to five times that of emery, but it is lighter and harder, and therefore goes farther. The Carborundum Co. maintain that their product does its work more quickly and neatly than emery.

CHAPTER XII

POTASH FROM THE ASH OF WOOD

When vegetable matters are burnt in a sufficiency of air a light white, grey, or pink ash is formed, consisting of the mineral constituents of the plants, which, on examination under a magnifying-glass, will be seen to retain the cellular structures of the vegetable tissues, proving that they are present in every part and are essential constituents. These mineral salts consist of potassium carbonate and sulphate, calcium carbonate and phosphate, and traces of iron, manganese, etc., varying in proportions according to the kind of plant and the organs from which they are derived.

Previous to the discovery of the German potash deposits the sole sources of potassium compounds were wood ashes and the ash of seaweeds (kelp), but as the German mineral potash industry developed, the other industries gradually dwindled, since they were quite unable to compete with it in the market in point of price, and it was only in very remote localities, where the materials were plentiful, that either the wood ash or kelp industries could be kept from total extinction. During the war, however, the conditions were suddenly altered; owing to the strictness of the blockade no potash salts could be sent out of Germany, and as that country had practically a world's monopoly of this commodity, great scarcity resulted in most other countries, so that the price of potash salts rose to fabulous figures. At this juncture every possible source of potash was examined, and renewed interest was taken in the original

raw materials—wood ash and kelp. Although certain species of plants and also certain parts of plants—*e.g.* seeds—contain a considerable amount of potash in the ash, the amount of potash obtained from various woods is comparatively small, hence it is only under very favourable circumstances that waste wood could be employed as the raw material from which to prepare it. The following are old analyses by various chemists giving the percentage of potash present in woods and other vegetable products :—[1]

	Per cent. of potash (K_2O).		Per cent. of potash (K_2O).
Pine	·045	Maize stalk	1·759
Poplar	·075	Bean stalk	2·000
Trefoil	·075	Stinging nettle	2·503
Beech	·145	Vetch	2·750
Beech bark	·600	Flax stems	·500
Oak	·153	Thistles	·500
,, bark from twigs	·420	,, in full growth	3·537
Box	·226	Cotton grass	·500
Willow	·285	Rush, small	·508
Elm	·390	,, large	7·22
Vine	·550	Bastard chamomile	1·96
Fern	·662	Sunflower stalks	2·00
Wheat straw	·390	Wormwood	7·30
,, ,, before flowering	4·700	Fumitory	7·90
Barley straw	·580		

The following analyses by Höss[2] are also worth quoting :—

	Ash	Potash (K_2O)
	Per cent.	
Pine wood	·34	·045
Beech ,,	·58	·127
Ash ,,	1·22	·074
Oak ,,	1·35	·150
Elm ,,	2·55	·390
Willow ,,	2·80	·285
Vines	3·40	·550
Ferns	3·64	·425
Wormwood	9·74	7·30
Fumitory	21·90	7·98

[1] Ure's *Dictionary of Arts, etc.*, 1853, 457.
[2] Watt's *Dictionary of Chemistry*, 1877, vol. iv. 709.

More recently analyses have been made of plant ashes by R. Berry,[1] which showed the following amounts per cent. of potash and phosphoric acid :—

Ash.	Potash (K_2O) Total.	Soluble in water.	Phosphoric acid (P_2O_5)
Bracken	20·45	10·61	3·37
Spruce	11·94	8·23	7·01
Hardwood (oak trimmings mostly)	3·53	2·75	—
Mixed forest produce	3·13	1·50	1·54
Soft wood, forest fire	11·79	6·53	5·23
Hard wood, boiler fire	10·44	6·77	5·02

J. C. Umney [2] suggested that waste vegetable products, such as furze, bracken, hedge clippings, etc., should be gathered systematically and burnt for the preparation of ash, from which potash could be extracted; it is doubtful, however, whether any better use for these materials could be found than spreading the ash on the land, when its fertilising constituents will be fully utilised. The ash of some of the vegetable wastes is, however, somewhat rich in potash, thus, according to Umney, the following percentages of potash are present :—

Ash	Potash (K_2O)
Bracken	60
Boletus edulis	50 to 57
Agaricus velutipes	78
Hypnum Schroberi	28 to 30
Groundsel	43·5
Broom	33
Euphorbia amygdaloides	39

Quaintenne [3] also states that mangrove trees growing in fresh-water marshes contain a notably high proportion of potash salts, and suggests that the ash of the wood may be used as a manure, or could be used in the manufacture of pearlash.

[1] *Jour. Board Agric.*, 1915, 766.

[2] J. C. Umney, *Jour. Soc. Chem. Indt.*, 1914, 1046. See also C. G. Cresswell, *ibid.*, 1915, 389.

[3] Quaintenne, *Chem. Trade Jour.*, December 12, 1914.

In Southern Russia a considerable amount of potassium carbonate was prepared by burning the stalks, etc., of the sunflower plant, which was grown for the sunflower oil industry, and then lixiviating with water. In 1907 there were in the Caucasus twenty-four factories devoted to this purpose, producing a total of 14,500 tons per annum of potassium carbonate.

It may be mentioned that although the production of potash from plant ashes has been known for a very long period, a patent was granted to Hudson in 1802 for extracting it from tanners bark, bean and other straw, fern, furze, broom, and also kelp.

Potassium carbonate is still made in small quantities in localities where wood is plentiful, such as Canada, North America, Hungary, and Russia, usually from waste wood, such as branches, twigs, etc., on the ground from which timber has been cleared. The method of preparation until recently was very simple and the product crude, the operations consisting of burning the wood in heaps, lixiviating the ash with water, and evaporating the clear solution to dryness in an iron pan or pot over an open fire, hence the name "potashes." This is an impure brown carbonate of potash containing 35 to 40 per cent. of carbonate and also sulphates and chloride. By treating the residue with a very small quantity of water most of the impurities are left undissolved, and on again evaporating to dryness and calcining in a reverberatory furnace to destroy organic matter, a purer form of potash is obtained, known as pearlash, which contains 50 to 55 per cent. of potassium carbonate, or sometimes even as much as 80 or 90 per cent.

H. Bradley [1] has made numerous analyses of the ashes of plants and woods, and he suggests that the waste produced by the Western U.S.A. sawmills should be utilised as a source of potash. He states that no less than 750,000

[1] H. Bradley, *Met. and Chem.*, Eng., 1915, 841.

tons of such waste, after allowing for what is sold for fuel purposes, is produced annually, from which could be extracted 1000 tons of potash. It must be remembered also that this waste could first be distilled in the usual manner, and the charcoal used as fuel under the stills, provided that a simple plant for extracting the dust from the flue gases was installed. A battery of extraction vessels should be provided for leaching out the ash with water arranged on the counter-current principle, *i. e.* pure water and spent ash at one end of the series, and fresh ash and concentrated lye at the other, the liquid passing from one vat to another until it reaches the last and is ready for evaporation. For the evaporation of the lye an apparatus of the Enderlein type is recommended, with a rotary roasting furnace of the type used in the recovery of soda and sulphate in wood-pulp establishments. The evaporator consists of an open evaporating pan of wrought iron, 16 feet in length, 7 feet in depth, and 14 feet in width, enclosed in a brick chamber, below which is the furnace. Two revolving shafts are arranged at the top of the pan, these being 7 feet apart, and each is provided with thirty-two wrought-iron discs $5\frac{1}{2}$ feet diameter, which dip into the liquid to the extent of about $\frac{1}{6}$th of their surface, and as they revolve carry the liquid with them, thus bringing the liquid into intimate contact with the air and facilitating evaporation. The liquor flows continuously in at one end of the evaporator and out at the other, over a weir into the rotary roaster, which is cylindrical and 16 feet long by 8 feet diameter, and which carries the liquid almost to dryness. The liquid then passes to a reverberatory furnace, in which it is converted into a more or less porous mass, which is subsequently roughly ground and graded into granular particles or powder, and forms the pearlash of commerce.

CHAPTER XIII

THE PRODUCTION OF WOOD-WOOL

In large saw-mills, carpentry and cabinet-making workshops, etc., a large amount of wood-refuse accumulates for which no immediate use can be found, and which in many cases is simply burnt. Any of these waste pieces not measuring more than $16\frac{1}{2}$ by $5\frac{3}{4}$ inches may be very advantageously worked up for wood-wool. Wood-wool consists of filaments of various degrees of fineness, with a correspondingly higher or lower elasticity. In the comparatively short time that has elapsed since it was introduced this material has already found extensive employment.

Wood-wool is a clean, dust-free, light, and very elastic packing material, which, compared with straw, hay, etc., has the advantage of not rotting so readily. Being specifically lighter than any other packing material, the quantity required is about 30 to 40 per cent. less. It is specially suitable for packing glass, porcelain, fancy goods, hardware, metal ware, perfumery, drugs, and medical preparations (in glass, and other vessels), and also for meat, sausages, fruit, eggs, flowers, etc.

Wood-wool is employed in metal foundries for wrapping round the loam moulds; it is also a very serviceable stable litter where straw is unobtainable, and is much to be preferred to either leaves or pine needles.

Wood-wool is used with advantage for stuffing cushions, since it retains its elasticity far better and longer than seaweed, hair, etc. The resin contained in the pine- and fir-woods, which are almost exclusively employed, protects

the articles stuffed with wood-wool from the attack of insects; moisture also has but small effect on this stuffing material. The investigations made by the Prussian War Office have shown that pine-wood fibre is a very agreeable, soft, and clean material for stuffing mattresses for hospitals and barracks, is highly appreciated by the sick and free from all the disadvantages which have hitherto been unavoidable.

Very fine wood-wool has quite recently been employed for surgical dressings, for which it has been found highly suitable. It also answers the purpose of a flesh brush, since it opens the pores of the skin and freshens and invigorates the surface. The very finest, the so-called lint-wool, is used in hospitals and infirmaries. The shavings produced by wood-wool machines serve also as a filtering material, for making vinegar, and for fire-kindlings: those made from hazel-wood are used in breweries; beech-wood shavings in vinegar factories; and pine-wood shavings for fire kindlings. Wood-wool is also used instead of cotton-waste for cleaning machinery, as it is considerably cheaper, and is far less liable to spontaneous combustion.

The machines employed for producing wood-wool may be adjusted so as to reduce it to a coarser or finer condition. The product may be dyed any colour by simply immersing it in a dye-bath, draining it on sieves and drying. Various colours may be obtained by the following formulæ :—

1. *Brown.*—Three parts of permanganate of potash are dissolved in 200 parts of cold distilled water, the wood-wool being immersed in the solution for a few minutes and then taken out and dried.

2. *Yellow.*—Five parts of ground turmeric root are boiled with 150 parts of water and ½ part of alum; the decoction is strained from the powder through a sieve and is then ready for use.

3. *Green.*—Two parts of soluble aniline green are dissolved in 250 parts of water.

4. *Blue.*—Two parts of soluble aniline blue are dissolved in 200 parts of water.

5. *Red.*—Two parts of soluble aniline red (eosin, ponceau, or rosein, according to the shade desired) are dissolved in 250 parts of water.

6. *Violet.*—Two parts of aniline violet are dissolved in 250 parts of water.

The best mode of procedure is to put the wood-wool in a large sieve, dip the whole into the dye-bath, then take it out and allow it to drain, after which the dyed wool is dried on wicker racks in a moderately heated chamber.

One of the best wood-wool machines is that of Anthon & Sons of Flensburg: it can be made double, triple, or quadruple acting. In the double-acting machines the carriage has no movable parts. These double-acting machines are employed wherever quantity rather than quality is required in the product, the reason for this distinction being that no piece of wood can be planed equally well in both directions, as any one can ascertain by trying the experiment with a hand plane, when it will be found that whilst cutting against the grain the shavings are not so smooth as those cut in the opposite direction. For coarse wood-wool this is of no consequence; but if, on the other hand, the object is to produce extra fine and delicate wool, such as the patent carriage of the machine is intended to yield, it is necessary that the machine should be single-acting, each piece of wood being introduced between the feed-rollers in the right direction for planing with the grain. A special advantage of this machine is that filaments of various widths can be obtained from it without the necessity of changing the slitting knives.

The whole machine (Fig. 46) is supported on a solid iron frame, which as a rule is arranged horizontally, being furnished with iron legs as shown in the figure. It can, however, where space considerations or the driving arrangements require, be set up in a sloping position. The frame

carries the driving-shaft with fast and loose pulleys, a crank and fly-wheel. By means of a connecting rod, the crank imparts a reciprocating motion to an iron carriage, which latter carries the very simple cutters, one or sometimes two broad plane irons, and a series of pointed knives, which are set to the required width of the filaments, and which produce longitudinal cuts in the wood, whilst the plane which follows them takes off a shaving from the already scored surface, the resulting wood-wool falling

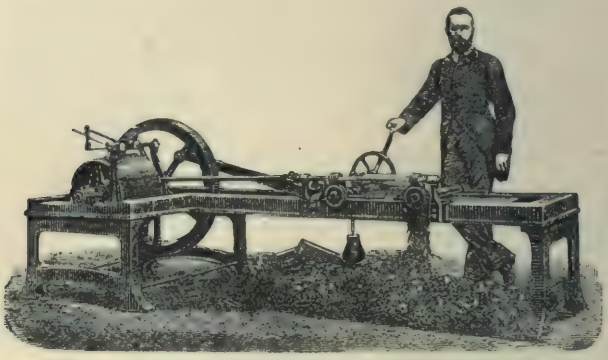

Fig. 46.—Double Acting Wood-wool Machine (Anthon & Sons).

from the machine. Two toothed rollers arranged transversely across the carriage, and revolving to a certain distance backwards for each movement of the latter, hold the wood which is to be planed, the roller nearest the crank being pressed against the wood by a rack and pinion acted on by a weight hanging from a cord which passes over a pulley, thus bringing the wood up to the plane through a definite distance at each cut. A lever connected with the pulley permits a more rapid to-and-fro motion of the pulley, and consequently a rapid backward and forward motion of the front roller, so that pieces of wood

of different lengths can be introduced under the rollers one after another without stopping the machine.

The machine can easily be attended by a single workman, who, after throwing the driving-belt upon the driving-pulley has merely to thrust one piece of wood after another between the rollers; this is done with the left hand, whilst the right hand moves the front roller nearer to or farther from the back roller, according to the length of the pieces.

When the rollers have seized the piece of wood it is unnecessary for it to be held by the hand any longer: the rollers push it forward automatically, so that, unless the pieces are very small, one workman can easily feed two machines. The machine has a length of $10\frac{1}{2}$ feet and a breadth of 3 feet 4 inches. The driving-pulley is 20 inches in diameter by 6 inches broad, and should turn at about 150 revolutions per minute. The output of a double-acting machine should amount, in 10 hours, to 6 to 12 cwt. of the coarsest wood-wool, according to the kind of wood: of finer wool a proportionally smaller quantity is produced. The thickness of the filaments is always the same; but if desired, different worm-wheels can be supplied at an extra cost, giving a variety of thicknesses, the most usual being 3, 5, 15, and 20 filaments to 1 millimetre. The width of the filaments can be regulated by either clamping the scoring knives close together, or by inserting distance pieces of any desired thickness between them. The power required for a wood-wool machine is 1 to 2 horse-power according to the yield.

The machine will take round, square, or flat pieces of wood of the following maximum dimensions: about 20 inches long by $5\frac{3}{4}$ inches wide, and, of course, pieces which are smaller in either direction. The thickness is not restricted, but it is nevertheless disadvantageous for it to exceed 20 inches. The material can be worked down to pieces of 1 inch in square section; the waste is therefore very small.

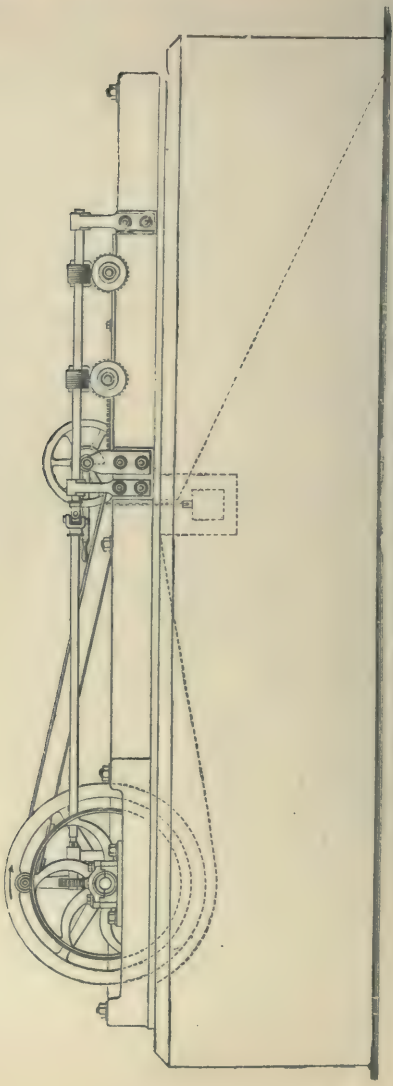

Fig. 47.—Wood-wool Machine (Front View).

The machine can be driven equally well by wind, water, steam, or any other power, and is capable of reducing cane to wool. It is not clear, however, that there is any advantage in working up cane into wool, for new cane is too costly, and short, thin pieces of waste cane are not profitable, because the yield is so small, and the wool would be very irregular. Trials have also proved that though cane in rods is elastic, the wool it yields possesses no greater elasticity than that from beech, oak, and other soft woods.

Another construction is so distinctly shown in elevation and plan in Figs. 47 and 48 as to require no further explanation. The length of the machine is about 10½ feet, its breadth 5¼ feet; the diameter of the driving-pulley is 20 inches and its width 6 inches; and the weight of the whole machine is about 12 cwt. For 150 revolutions per minute it requires 1 to 2 horse-power, and in 10 working hours will turn out 5 to 9 cwt. of wood-wool.

The improved quadruple-acting wood-wool machine of Anthon & Sons consists of a very strong frame, which is set on a brick foundation, or in cases where a brick foundation cannot be used, a strong wooden frame, or a cast-iron base may be employed. It is, however, always better, where possible, to set it on a brick foundation, as it will then work steadily and quietly even at a high speed. Gearing and machine are connected by a wrought-iron connecting rod. All the shafts, etc., are of steel; the carriage runs in exchangeable and adjustable guides; the knives are arranged vertically, and are divided into two sets, each consisting of a plane cutter and a toothed knife, which works immediately in front of it, and acts on two pieces of wood. The one set of knives cuts during the forward motion, the other during the backward motion, but each of them on a separate piece of wood. The rollers are divided into three groups, the middle one of which consists of two fixed rollers covering the whole width of the carriage, and taking the thrust of the knives, whilst

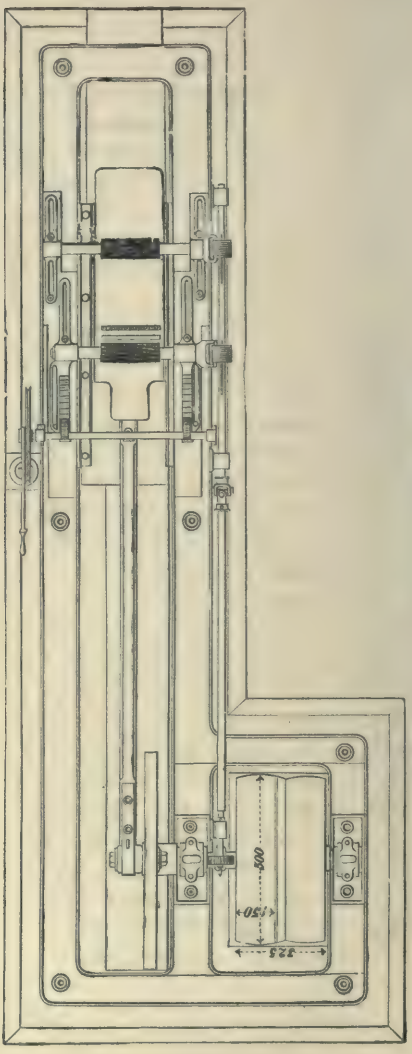

FIG 48.—Wood-wool Machine (Plan).

the two outer groups are divided in the middle, so that each short roller serves for holding a separate piece of

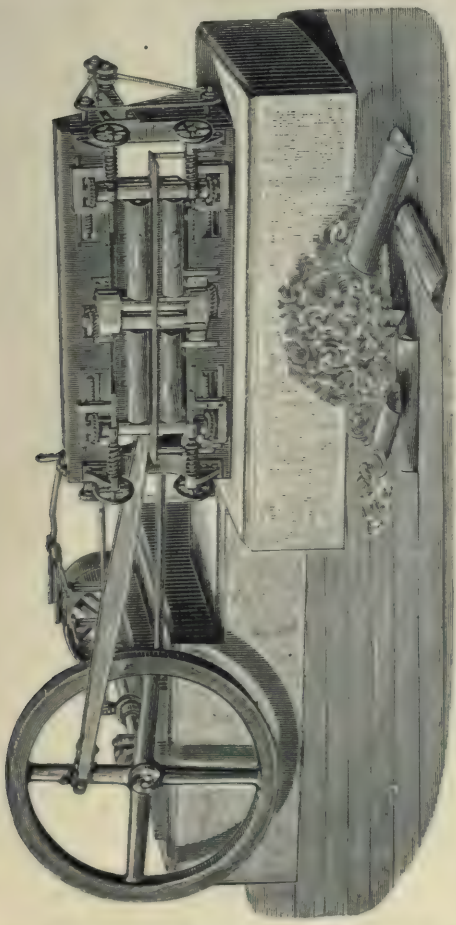

Fig. 49.—Quadruple Wood-wool Machine without Scribing Knives.

wood and is separately controlled by a hand-wheel and screw. A thin plate divides the face of the plane into

upper and lower halves; this serves at the same time as a bed for both the upper pieces of wood, and can be removed if thicker blocks of wood are to be worked up. The following additional parts are supplied with each machine :—

Interchangeable wheels for producing seven different sizes of wood-wool, varying from $\frac{1}{2}$ to $\frac{1}{15}$ millimetre in thickness. Two plain and two toothed plane knives of 12 or $13\frac{3}{4}$ inches long. The teeth are arranged for producing filaments 2 millimetres wide. To produce either wider or narrower filaments toothed knives of different sizes must be inserted.

Vertical Wood-wool Machine (Ernst Kirchner & Co.).—This machine is especially advantageous in places where there is but little space, or where the driving-shaft is high up, or where a cheap machine is required, from which an abundant output is not of special importance.

The machine is similar to the single-acting machine, with the difference that it is set up in a vertical position and is mounted on a wooden frame. In small establishments, where wood-wool is prepared, not as an article of commerce but for home consumption, this machine will suffice in many cases. The machine is constructed with either one or two cutters. The figure shows a pattern with one cutter. In the machine with two cutters the fast and loose pulleys are arranged between the two crank-wheels, so that there are cutters both to the right and left of the driving-pulley, and two pieces of wood can be shredded into wool at the same time. The cranks of the two crank-wheels are set 180° apart.

The machine is manufactured of three different sizes for pieces of wood up to 20, 24, and 28 inches in length. The power required is 2 to 4 horse-power.

Rotary Wood-wool Machine of Otto Camillo Israel, Vienna.—This machine is built with a strong cast-iron base, which enables it to be run at 250 revolutions per minute. In the vertical knife-wheel there are 4 sets of

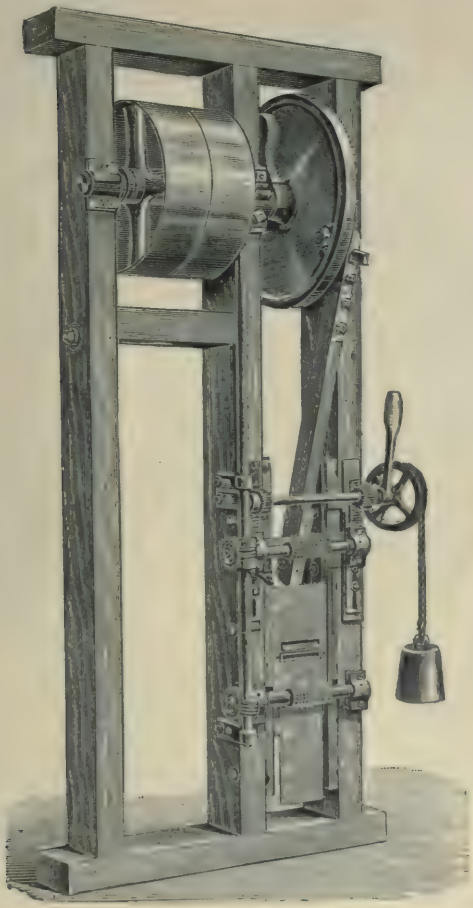

Fig. 50.—Vertical Wood-wool Machine (Kirchner & Co., Leipsic).

toothed knives alternating with 4 plain knives. A sheet-iron screen covers this knife-wheel for the protection of the workman from injury. The pieces of wood, 10 inches

long by $4\frac{3}{4}$ inches thick, and of any width, are brought into contact with the knives by two grooved wheels. By changing the knife-wheels, seven sizes, and by changing the toothed knives, fourteen sizes of wool can be produced. The output is the same as that of a triple-acting machine.

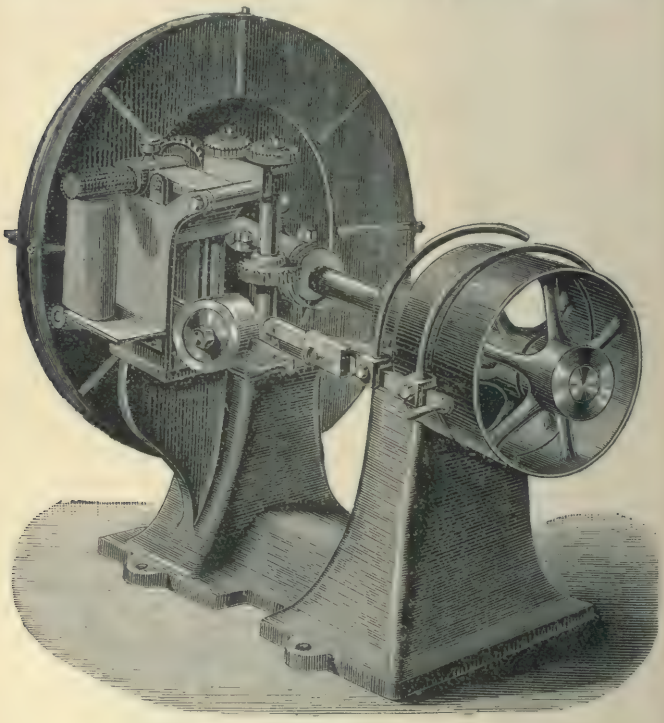

Fig. 51.—Rotary Wood-wool Machine.

Utilisation of Bark.—Tree bark, especially that of the oak and coniferous trees, and also of the birch, willow, and elm, is not to be regarded as a mere waste product, since in many places it finds extensive application as a tanning material.

Nevertheless, in localities where there are no facilities for carriage, bark must be regarded as a waste product which can only be utilised as fuel. In such cases it is, however, profitable to extract the tannin, the carriage of which presents less difficulty. This extract can be employed for tanning with the same result as bark itself, and since 100 parts of extract are quite as efficient as 400 to 500 parts of bark, it follows that its higher commercial value allows it to be delivered to the consumer at far greater distances than is the case with bark.

In his work on *Die Verwerthung des Holzes auf chemischen Wege* (The Utilisation of Wood by Chemical Methods) Dr. Bersch says: "In order that tannin extracts may meet with general approval by tanners, at least two conditions must be fulfilled: The extracts must invariably be sent out of the same quality and containing a definite percentage of tannin, and the tanner must be made acquainted with the mode of employing the new material. If the tanner can be assured that 1 lb. of the extract will have exactly the same tanning efficiency as a definite number of pounds of the best coppice bark, practical men will very soon accustom themselves to employ the extract instead of bark. The introduction of the extraction process furnishes, moreover, the proprietors of forest lands with a means of bringing the one valuable constituent of bark, *i. e.* the tannin, into such a form that it can be delivered at great distances, whilst the use of the extract affords the tanner the immense convenience of being able to work with rapidly prepared solutions of the material, instead of having, as formerly, first to extract the tannin from the bark. Furthermore, the large spaces required for the storage of bark, the drying of the spent tan, etc., are rendered quite superfluous."

In this connection the author merely indicates here the mode in which the bark, when it has to be regarded as a waste product, can be utilised, whilst for further particulars

respecting the preparation of tannin extracts the reader is referred to the above-mentioned treatise by Dr. Bersch.[1]

Utilisation of Birch-bark.—The bark of the birch can be employed as a tanning agent in the same way as that of other trees. When birch-bark is submitted to dry distillation the usual products : gases, pyroligneous acid, and tar are obtained, but the proportion of tar is somewhat considerable, amounting to about 60 per cent. of the weight of the bark employed. Birch-tar, or the product of its redistillation, birch-tar oil, has a very characteristic odour, which will be recognised as that of Russia leather, this leather being prepared with birch-tar. Fancy goods made from imitation Russia leather are also treated with birch-tar to give them the characteristic odour of the genuine article.

The distillation of the bark is best carried on in large iron pots, with an alembic head and cooling worm coil. In this way the pyroligneous acid and tar are completely and easily collected, and the distillate, when left in repose, separates into two sharply defined layers. Seeing that the yield of acetic acid from the distillation of bark is comparatively trifling, it is not worth while to work it up for the production of acetic acid at the spot, so it is collected and sent to factories where the manufacture of wood-vinegar is a special feature.

Besides these modes of utilising bark, it is employed for architectural and decorative purposes. In forest districts, summer houses are either wholly built of bark or of a wood framework covered with bark; also baskets for plants in pots, etc., are made from bark, and command a ready sale.

Wood Flour.—The manufacture of wood flour is an industry which has developed to some little degree of importance in the United States and Scandinavia. It is

[1] See also *Wood Products, Distillates and Extracts,* by P. Dumesny and J. Noyer. Published by Scott, Greenwood & Son, London.

prepared from non-resinous woods such as white pine, spruce, and poplar, which lend themselves to ready comminution. The bark is first stripped from the wood, and the latter is converted into chips, which are ground to powder between millstones or in steel roller mills. In Scandinavia the former type of mills predominate, these being driven by water-power turbines. In order to reduce the risk of firing, either steam or water is admitted to the interior of the mills in sufficient quantity to prevent dusting, while the finely powdered material is sucked or blown by a fan through pipes into a chamber containing metallic or silk gauze screens, which filter out the wood flour and allow the air to escape. The wood flour falls from the sieves into the hopper at the bottom of the chamber, from which it passes to automatic sacking and weighing machinery. Wood flour is used for a variety of purposes, but more particularly for the manufacture of dynamite, linoleum, and plastic flooring compositions. It is an excellent absorbent for liquids, and in the case of dynamite a good quality of wood flour will absorb 60 or even 70 per cent. of nitroglycerine without any of the latter exuding. Typical dynamites are composed of 15 to 18½ per cent. of wood flour, 40 to 61 per cent. of nitroglycerine, 19 to 44 per cent. of sodium or potassium nitrate, and 1 to 1½ per cent. of carbonate of lime. Wood flour is used in place of cork dust in the manufacture of inlaid linoleums, since it has a much lighter colour, but it is 50 to 100 per cent. heavier. In the United States over 4000 tons of wood flour was used in the manufacture of dynamite, and it is estimated that the amount used for the same purpose in 1909 was over 9000 tons. It is also stated that about 4,460,000 square yards of inlaid linoleum containing 40 to 50 per cent. of wood flour was manufactured in the United States in 1909.[1]

[1] F. W. Kessman, *Met. and Chem., Eng.*, 1916, 372.

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